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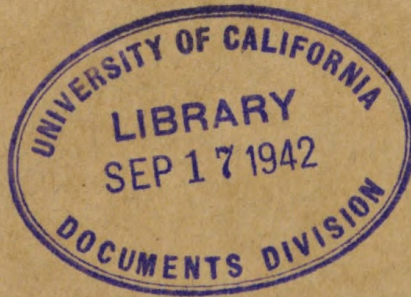
U.S. WAR DEPARTMENT

U.S. Dept. of Army

TECHNICAL MANUAL

HEAT TREATING AND INSPECTION  
OF METALS

September 10, 1941





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## HEAT TREATING AND INSPECTION OF METALS

Prepared under direction of the  
Chief of the Air Corps

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## SECTION I

## PRINCIPLES OF HEAT TREATING

|              | Paragraph |
|--------------|-----------|
| General..... | 1         |

1. **General.**—*a.* Heat treatment is a series of operations, involving the heating and cooling of a metal, or alloy in the solid state, for the purpose of obtaining certain desirable characteristics. The rate of heating and cooling determines the crystalline structure of the



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## HEAT TREATING AND INSPECTION OF METALS

CHANGES }  
No. 1 }

U.S. WAR DEPARTMENT,  
WASHINGTON, March 10, 1942.

TM 1-423, September 10, 1941, is changed as follows:

1. **General.**—*a.* Heat treatment is a series of operations, involving the heating and cooling of a metal, or alloy in the solid state, for the purpose of obtaining certain desirable characteristics. The rate of cooling determines the crystalline structure of the material. In general, both ferrous and nonferrous metals \* \* \* to produce the desired change.

\* \* \* \* \*  
[A. G. 062.11 (1-10-42).] (C. 1, Mar. 10, 1942.)

### 6. Hardening.

\* \* \* \* \*  
*e.* A number of liquids may be used \* \* \* where many articles are to be quenched in succession.

#### (1) *Quenching procedure.*

\* \* \* \* \*  
(*d*) Irregularly shaped sections should be immersed in such a manner that the parts of the greatest section enter the bath first.

#### (2) *Quenching media.*

\* \* \* \* \*  
(*b*) Salt brine is used where a comparatively rapid cooling rate is necessary, as in the case of low carbon steel. The mixture is made by dissolving ordinary salt in water until a 10 percent solution is obtained.

\* \* \* \* \*  
[A. G. 062.11 (1-10-42).] (C. 1, Mar. 10, 1942.)

7. **Tempering.**—*a.* Steel in the hardened state may be considered \* \* \* troostite gradually changes into sorbite. At 1,100°, the transformation of troostite into sorbite is complete. Pearlite is obtained by slow cooling from the critical point as in annealing.

\* \* \* \* \*  
[A. G. 062.11 (1-10-42).] (C. 1, Mar. 10, 1942.)

8. **Annealing and normalizing.**—*a. Annealing.*—When steel is heated to a point above its critical range \* \* \* each being normal for a particular range of temperatures. **Austenite decom-**

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poses to to one of the following structures depending on the rate of cooling: martensite, troostite, sorbite, and finally pearlite.

\* \* \* \* \*

[A. G. 062.11 (1-10-42).] (C. 1, Mar. 10, 1942.)

### 9. Case hardening.

\* \* \* \* \*

*c. Nitriding.*—(1) This method of case hardening is advantageous due to the fact that a harder case is obtained than by carburizing. Many engine parts such as cylinder barrels, gears, etc., may be treated in this way. Nitriding can only be applied to certain special steel alloys, one of the essential constituents of which is aluminum. The process involves \* \* \* the composition of which is given in table IV.

\* \* \* \* \*

[A. G. 062.11 (1-10-42).] (C. 1, Mar. 10, 1942.)

### 15. Nickel steel (SAE 2330).

\* \* \* \* \*

*b. Hardening.*—In hardening nickel steel, the furnace temperature should not exceed 1,100° F. when the parts are inserted; the temperature must then be gradually increased to 1,430°–1,500° F. This steel should be quenched in oil.

\* \* \* \* \*

[A. G. 062.11 (1-10-42).] (C. 1, Mar. 10, 1942.)

### 16. Chrome-molybdenum steel (SAE X-4130 and X-4135).

\* \* \* \* \*

*c. Tempering.*—Hardened parts may be tempered \* \* \* is accomplished in still air.

| <i>Tempering temperature</i><br>(°F.) | <i>Ultimate strength</i><br>(pounds per square inch) |
|---------------------------------------|------------------------------------------------------|
| 1,075-----                            | 125,000                                              |
| 1,000-----                            | 150,000                                              |
| 800-----                              | 180,000                                              |
| 650-----                              | 200,000                                              |

[A. G. 062.11 (1-10-42).] (C. 1, Mar. 10, 1942.)

### 18. Chrome-nickel steel (SAE 3140).

\* \* \* \* \*

*b. Hardening.*—After inserting the parts in the furnace at a temperature of 1,100° F. or less, the heat should be gradually increased to between 1,475° and 1,525° F., which is the required hardening



temperature. After the soaking period the parts should be removed from the furnace and quenched in oil.

*c. Tempering.*—The ultimate strength produced \* \* \* should be well below the tempering temperature.

| <i>Tempering temperature</i><br>(°F.) | <i>Ultimate strength</i><br>(pounds per square inch) |
|---------------------------------------|------------------------------------------------------|
| 1,050-----                            | 125,000                                              |
| 950-----                              | 150,000                                              |
| 800-----                              | 180,000                                              |

[A. G. 062.11 (1-10-42).] (C. 1, Mar. 10, 1942.)

## 21. Chrome-nickel steel (SAE 3435).

\* \* \* \* \*

*b. Hardening.*—Hardening is accomplished by gradual heating to a temperature of 1,400° to 1,450° F., followed by an oil quench.

\* \* \* \* \*

[A. G. 062.11 (1-10-42).] (C. 1, Mar. 10, 1942.)

## 33. Alloy 17S.

\* \* \* \* \*

*e. Hardening.*

\* \* \* \* \*

(4) Age at room temperature for 24 hours. (Ninety percent of the maximum hardness is obtained in this time; maximum hardness is obtained in 4 days.)

[A. G. 062.11 (1-10-42).] (C. 1, Mar. 10, 1942.)

## 35. Alloy 24S.

\* \* \* \* \*

*e. Hardening.*

\* \* \* \* \*

(4) Age at room temperature for 16 to 24 hours. (Ninety percent of the maximum hardness is obtained in this time; maximum hardness obtained in 4 days.)

[A. G. 062.11 (1-10-42).] (C. 1, Mar. 10, 1942.)

## 37. Alloy 25S.

\* \* \* \* \*

*e. Hardening.*

\* \* \* \* \*





## TECHNICAL MANUAL

(4) Age artificially at a temperature between 285° and 315° F. for from 8 to 12 hours.

TABLE VI.—Soaking period for 17S, 17S Alclad, 24S, and 25S alloys

| Thickness of material (inches) | Minimum time of soaking for solution treatment (minutes) |           |
|--------------------------------|----------------------------------------------------------|-----------|
|                                | Air furnace                                              | Salt bath |
| . . . . .                      | . . .                                                    | .         |

[A. G. 062.11 (1-10-42).] (C. 1, Mar. 10, 1942.)

BY ORDER OF THE SECRETARY OF WAR:

G. C. MARSHALL,  
*Chief of Staff.*

OFFICIAL:

J. A. ULIO,  
*Major General,*  
*The Adjutant General.*



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TECHNICAL MANUAL

HEAT TREATING AND INSPECTION OF METALS

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CHANGES  
No. 2

WAR DEPARTMENT,  
March 10, 1943.

TM 1-423, September 10, 1941, is changed as follows:

5. Temperature measurement and control.

\* \* \* \* \*

b.

\* \* \* \* \*

(2) Pyrometers may be \* \* \* or recording type. Indicating pyrometers, such as shown at (2) in figure 3, give direct readings of the furnace temperature, while the recording type, such as shown at (3) in figure 2, gives a permanent record of the temperature range throughout the heating operation. Most pyrometer installations \* \* \* as a relay.

[A. G. 062.11 (3-6-43).] (C 2, Mar. 10, 1943.)

29. Heat treatment of rivets.—Rivets requiring heat \* \* \* coldest water available. Rivets removed from the cold water and held at room temperature may be headed or driven for a period of approximately 1 hour without cracking, and will harden completely in about 24 hours due to the effects of aging. Rivets made from \* \* \* they are received.

[A. G. 062.11 (3-6-43).] (C 2, Mar. 10, 1943.)

BY ORDER OF THE SECRETARY OF WAR:

G. C. MARSHALL,  
*Chief of Staff.*

OFFICIAL:

J. A. ULIO,  
*Major General,  
The Adjutant General.*



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material. In general, both ferrous and nonferrous metals as well as their alloys respond to some form of heat treatment and this fact is made use of to a great extent in the manufacture of aircraft parts and assemblies. Most all metals have a critical temperature at which the grain structure changes. Successful heat treatment, therefore, depends largely on a knowledge of these temperatures as well as the time required to produce the desired change.

b. Heat treatment involves a cycle of events which may be described as follows:

(1) *Heating*.—Heating a metal to a temperature within or above its critical temperature under carefully controlled conditions.

(2) *Soaking or holding*.—Keeping a metal at an elevated temperature for a definite time, in order that it may become thoroughly saturated with heat, and permit the necessary changes in grain structure to take place.

(3) *Cooling*.—Returning a metal to room temperature by quenching in air, brine, water, oil, etc.

c. The most common forms of heat treatment for ferrous metals are: annealing, normalizing, hardening, tempering, and case hardening.

(1) Annealing is used to reduce stresses, induce softness, alter ductility, or refine the grain structure. Maximum softness in metal is accomplished by heating it to a point above the critical temperature, holding at this temperature until the grain structure has been refined, followed by slow cooling.

(2) Normalizing is a process whereby iron base metals are heated above their critical temperature to obtain better solubility of the carbon in the iron, followed by cooling in still air.

(3) Hardening is accomplished by heating the metal slightly in excess of the critical temperature, then rapidly cooling by quenching in oil, water, or brine. This treatment produces a fine grain structure, extreme hardness, maximum tensile strength, and minimum ductility. Generally, material in this condition is too brittle for most practical uses, although this treatment is the first step in the production of high strength steel.

(4) Tempering (drawing) is a process generally applied to steel to relieve the strains induced during the hardening process. It consists of heating the hardened steel to a temperature below the critical range, holding this temperature for a sufficient period, then cooling in water, oil, or air. In this process, the degrees of strength, hardness, and ductility obtained, depends directly upon the temperature to which the steel is heated.

High tempering temperatures improve ductility at the sacrifice of tensile, yield strength, and hardness.

(5) Several special treatments may be given to iron base alloys to produce a hard, wear-resistant surface, and at the same time, leave the core of the metal tough and resilient. Such treatments are known as case hardening, and three common methods are as follows:

(a) *Carburizing*.—This method consists of holding the metal at an elevated temperature while in contact with a solid, liquid, or gaseous material rich in carbon. The process requires several hours, as time must be allowed for the surface metal to absorb enough carbon to become high carbon steel.

(b) *Nitriding*.—This process consists of holding special alloy steel at temperatures below the critical point in anhydrous ammonia. Absorption of nitrogen as iron nitride into the surface of the steel produces a greater hardness than carburizing but the hardened area extends to a lesser depth.

(c) *Cyaniding*.—This is a rapid method of producing surface hardness on an iron base alloy of low carbon content. It may be accomplished by immersion of the steel in a molten bath of cyanide salt, or by applying powdered cyanide to the surface of the heated steel. The temperature of the steel during this process should range from 1,300° F. to 1,600° F., depending upon the type of steel, depth of case desired, type of cyanide compound, and time exposed to the cyanide.

## SECTION II

### HEAT-TREATING EQUIPMENT

|                                          | Paragraph |
|------------------------------------------|-----------|
| General.....                             | 2         |
| Furnaces.....                            | 3         |
| Quenching tanks and liquids.....         | 4         |
| Temperature measurement and control..... | 5         |

**2. General.**—Equipment necessary for heat treating consists of a suitable means for bringing the metal to the required temperature, a temperature measuring device, and a quenching medium. Heat may, in some instances, be supplied by means of a forge or welding torch; however, for the treatment required in aircraft work a furnace is necessary.

**3. Furnaces.**—a. Heat-treating furnaces are of many designs and no one size or type perfectly fills every heat-treating requirement. The size and quantity of metal to be treated and the various treatments required determine the size and type of furnace most suitable for each.



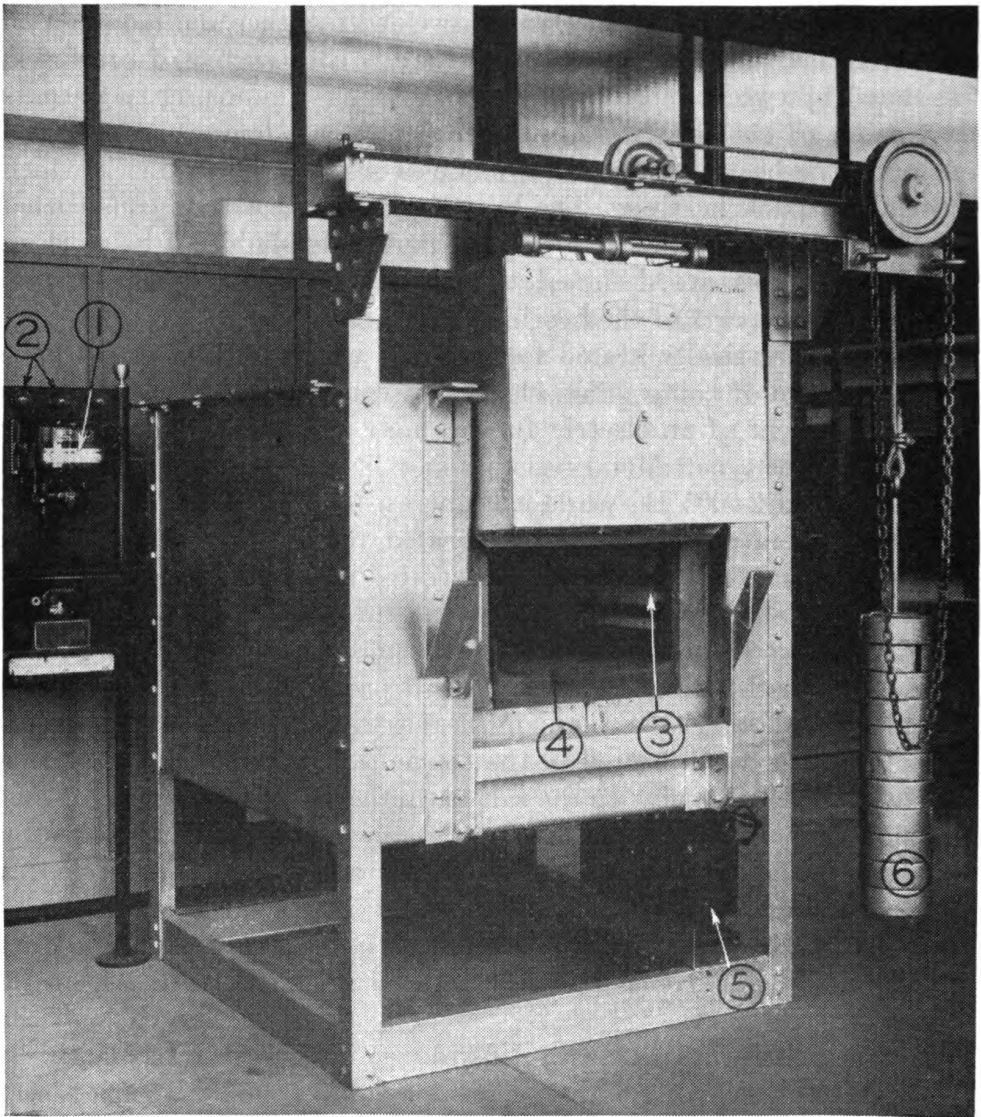
individual case; however, the general construction of the furnaces is very similar.

(1) Furnaces may be heated by means of oil, gas, or electricity. In the oil- and gas-fired types, the furnace proper or fire box is inclosed in a casing of steel plates, electrically welded together and mounted on a steel frame. The lining of the furnace is constructed of fire brick, insulated by two or more inches of magnesia. The magnesia permits expansion of the brickwork without danger of damage to the steel casing. The heating chamber is made of semirefractory brick which allows for quick heating. The hearth plates are usually constructed of a heat-resisting alloy with suitable flanges for holding the work in place. Furnaces are designed to maintain a uniform temperature throughout all parts of the heating chamber.

(2) The electrically heated furnaces are used extensively and have the advantage of being quiet, clean, and constant in operation. The heating element of an electric furnace may be either of the metal or carbon resistor type. Metal resistors may be used where temperatures do not exceed 2,000° F., while carbon resistors are recommended for higher temperatures. Electrically heated furnaces are illustrated in figures 1, 2, and 3. The furnaces illustrated in figures 1 and 2 are conventional production types, whereas the furnace shown in figure 3 is usually used in laboratories for experimental purposes.

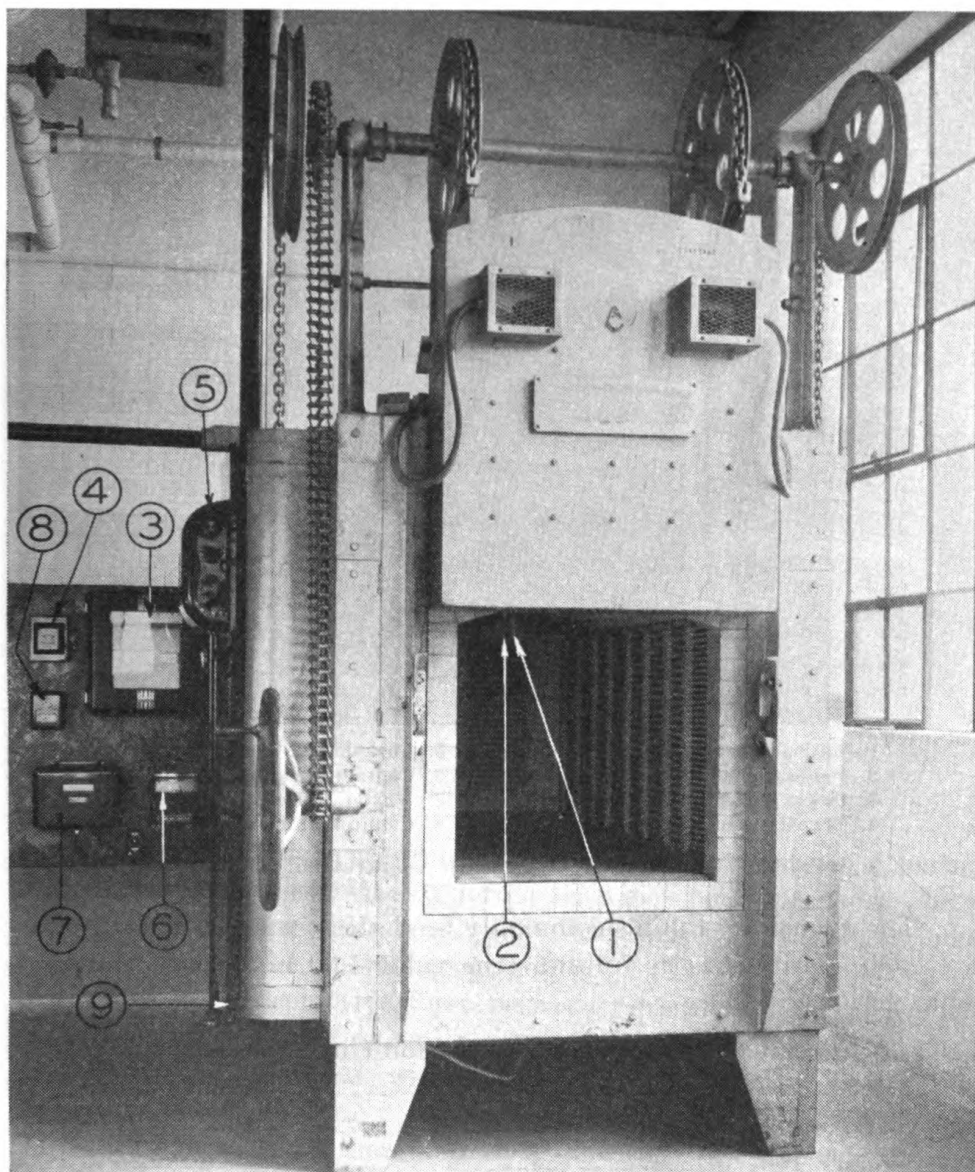
b. A salt bath is often used for small parts that have been finish-machined and for rivets requiring heat treatment. Parts and assemblies too large to be heated in the conventional furnace may also be treated in this manner. In the salt bath, the parts are heated by submersion in molten salt, which is kept at the required temperatures by means of electrical resistors. Figure 4 is a schematic drawing of a furnace used for this purpose which is simply a large crucible surrounded by fire brick. Parts heated in the salt bath are free from scaling although extreme care must be used to remove all traces of the salt after treatment.

**4. Quenching tanks and liquids.**—a. Suitable tanks must be provided for quenching baths. The size of tanks should be sufficiently large to allow the liquids to remain approximately at room temperature. Circulating pumps and coolers may be used for maintaining approximately constant temperatures where a large amount of quenching is done. The location of these tanks is very important due to the fact that insufficiently rapid transfer from the furnace to the quenching medium may destroy the effects of the heat treatment in many instances. A washing tank and provisions for scrubbing must also be provided for parts that have been heat-treated in salt brine.



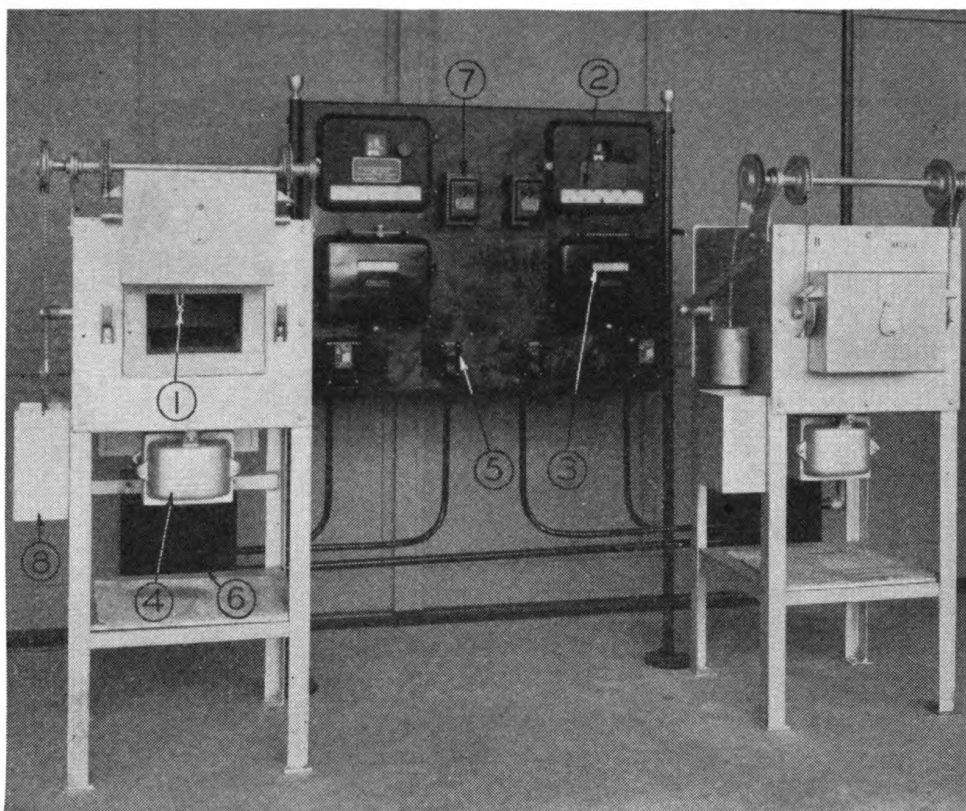
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|--------------------------|---------------------------------------|
| 1. Indicating pyrometer. | 4. Heat-resisting alloy hearth plate. |
| 2. Warning lights.       | 5. Transformers.                      |
| 3. Heating elements.     | 6. Counterbalance door weights.       |

FIGURE 1.—Electric heat-treating furnace.



- |                                             |                                |
|---------------------------------------------|--------------------------------|
| 1. Pyrometer thermocouple.                  | 5. Main line switch.           |
| 2. Excess temperature cut-out thermocouple. | 6. Excess temperature cut-out. |
| 3. Recording pyrometer.                     | 7. Power input controller.     |
| 4. Control circuit switch.                  | 8. Solenoid relay.             |

FIGURE 2.—Heavy duty type electric heat-treating furnace.



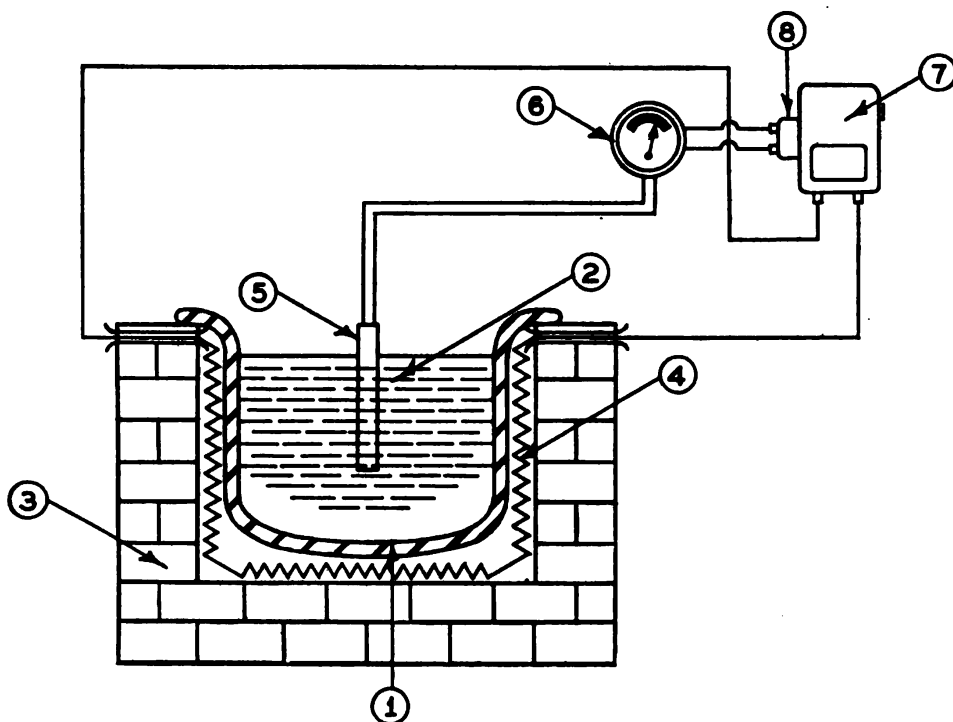
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|----------------------------|----------------------------|
| 1. Thermocouple.           | 5. Push button control.    |
| 2. Indicating pyrometer.   | 6. Contactor panel.        |
| 3. Power input controller. | 7. Master switch.          |
| 4. Transformers.           | 8. Counterbalance housing. |

FIGURE 3.—Laboratory type electric heat-treating furnaces.

*b.* The quenching liquids commonly used along with their comparative cooling rates are as follows (the value 1.00 represents the most rapid action):

|                                               |      |
|-----------------------------------------------|------|
| A 10 percent sodium chloride solution (brine) | 1.00 |
| Water at 70° F                                | .76  |
| Cotton seed oil                               | .27  |
| Neat's-foot oil                               | .25  |
| Fish oil                                      | .23  |
| Paraffin oil                                  | .20  |
| Machine oil                                   | .17  |

**5. Temperature measurement and control.**—*a.* Extreme care must be used in the control of temperatures for heat treatment, as a few degrees variation in temperature often seriously affects the physical properties of the metal.



- |                      |                                   |
|----------------------|-----------------------------------|
| 1. Crucible.         | 5. Thermocouple.                  |
| 2. Molten salt bath. | 6. Pyrometer.                     |
| 3. Fire brick case.  | 7. Master control switch.         |
| 4. Heating elements. | 8. Automatic temperature control. |

FIGURE 4.—Salt bath type heat-treating furnace.

*b.* In order to obtain accurate results, it is necessary to use a thermoelectric instrument known as a pyrometer which measures the electrical effect of a thermocouple, and hence, the temperature of the metal being heated. The operating principle of this device involves the difference in electromotive force between pure metals and alloys and may be explained as follows:

(1) If two dissimilar wires are joined together by twisting or welding, then heated, an electromotive force or voltage is generated. This voltage may be measured by connecting the opposite or cold ends of the wires to a galvanometer or millivoltmeter sensitive enough to read in thousandths of a volt. The strength of this current is proportional to the difference in temperature between the hot and cold ends. As the pyrometer is calibrated in degrees of temperature instead of electrical units, it therefore measures heat. A complete pyrometer consists of a thermocouple, extension leads and a meter.

(a) *Thermocouple.*—In general, the lower priced iron, copper, nickel, or chromium combination thermocouples are used for

temperatures up to 2,000° F., while the more expensive platinum and rare metal combination may be used up to a temperature of 3,000°. Following are details of common thermocouple with data on their characteristics:

| Electropositive         | Electronegative | Corresponding leads |               | Useful temperature range ° F. | Remarks                                          |
|-------------------------|-----------------|---------------------|---------------|-------------------------------|--------------------------------------------------|
|                         |                 | 1                   | 2             |                               |                                                  |
| Chromel----             | Alumel-----     | Copper--            | Constantan--  | 300° to 2,200°.               | Must be kept protected from reducing atmosphere. |
| Iron-----               | Constantan--    | Iron----            | Constantan--  | 300° to 1,400°.               |                                                  |
| Platinum-rhodium alloy. | Platinum---     | Copper--            | Copper alloy. | 0° to 2,650°.                 | Must be protected by neutral atmosphere.         |
| Copper-----             | Constantan--    | Copper--            | Constantan--  | 300° to 650°.                 |                                                  |

(b) *Extension leads*.—Alloy extension leads are made of flexible or solid wire of the same material as the couple, thus, in effect the thermocouple may be considered as extending from the furnace to the meter. By the use of extension leads, the meter may be placed a considerable distance from the furnace so that the cold ends will not be subjected to sudden fluctuations in temperature. The leads are carried in parallel and covered with a heat-resisting insulation.

(c) *Meter*.—Since a pyrometer does not indicate the actual temperature of the hot end of the thermocouple, but rather the difference in temperature between the hot and cold ends, the temperature of the cold end must be held constant and must be known. This is accomplished either by the use of a thermostat which is connected to a control spring in the instrument and makes the correction automatically, or by means of a zero adjuster which is operated manually. If the temperature of the cold junction of the thermocouple is constant, the millivoltage (caused by the difference in temperature between the hot and cold wire ends), will be proportional only to the temperature of the cold junction. If, however, the temperature of the cold junction is not kept constant or compensated for, the indications of the pyrometer will not be correct and will vary with fluctuations of the temperature surrounding the cold end. For example, if the temperature

of the cold junction at the instrument changes from 75° to 100°, the instrument will read 25° too low. It may, therefore, be seen that an increase of temperature at the cold end means a corresponding decrease at the hot end. The interior construction of the pyrometer includes a coil of enameled copper wire supported vertically on two polished steel pivots, resting in jeweled bearings and swinging between the pole pieces of a tungsten steel magnet. When the welded junction of the thermocouple is heated, a small current is generated causing a deflection of the movable coil, which moves the pointer across the scale.

(2) Pyrometers may be either of the indicating or recording type. Indicating pyrometers, such as shown at (2) in figure 3, give direct readings of the furnace temperature while the recording type, such as shown at (1) in figure 1, gives a permanent record of the temperature range throughout the heating operation. Most pyrometer installations on modern furnaces provide automatic regulations of the temperature at any desired setting. Instruments of this type are termed "controller potentiometer pyrometers" and include a current regulator as well as an operating mechanism such as a relay.

### SECTION III

#### GENERAL HEAT TREATMENT OF STEEL

|                                | Paragraph |
|--------------------------------|-----------|
| Hardening-----                 | 6         |
| Tempering-----                 | 7         |
| Annealing and normalizing----- | 8         |
| Case hardening-----            | 9         |

**6. Hardening.**—*a.* Heat treatment considerably transforms the grain structure of steel and it is while passing through a critical temperature range that steel acquires hardening power. When a piece of steel is heated slowly and uniformly beyond a red heat, its appearance will increase in brightness until a certain temperature is reached; at this point a phenomenon known as "decalescence" occurs. The color will change slightly, becoming somewhat darker, which may be taken as an indication that a transformation is taking place within the metal; pearlite is being converted into a condition known as austenite. When this change of state is complete, the steel will continue to increase in brightness, and if cooled quickly to prevent the change from reversing, hardness will be produced. If, instead of being rapidly quenched, the steel is allowed to cool slowly, the metal will again pass through a change of state and the cooling rate will be momentarily arrested. This is a phenomenon known as "recalescence" and indicates that the



austenite is being converted into pearlite. The terms "decalescence" and "recalescence" may be further defined as follows, using eutectoid steels (steels having a 0.85 carbon content) as an example:

(1) *Decalescence*.—When a piece of steel is heated, the temperature rises uniformly until it reaches a point between 1,325° and 1,350° F. At this point, the rise in temperature suddenly halts due to the fact that the metal absorbs the heat necessary for the change of state. After this halt, the temperature will continue its normal rate of increase. It is the halting in the temperature range that is termed decalescence. At the point of decalescence, the carbon and iron is forming a solid solution, and the steel is passing from its annealed condition into its hardening condition.

(2) *Recalescence*.—When steel is slowly cooled from a point above the critical temperature, the cooling proceeds at a uniform rate until the piece reaches a point between 1,250° and 1,300° F. At this time, the cooling is noticeably arrested and the metal acutally rises in temperature as the change of state again takes place. This change is the opposite of decalescence and is termed recalescence.

b. In order to obtain a condition of maximum hardness, it is necessary to raise the temperature of the steel sufficiently high to cause the change of state to fully complete itself. This temperature is known as the "upper critical point" and is given for the principal aircraft steels in a subsequent portion of the text. Steel that has been heated to its upper critical point will harden completely if rapidly quenched; however, in practice it is necessary to exceed this temperature by from 25° to 50° F., to insure thorough heating of the inside of the piece. If the upper critical temperature is exceeded too much, an unsatisfactory coarse grain size will be developed in the hardened steel.

c. Successful hardening of steel will largely depend upon the following factors:

(1) Control over the rate of heating, specifically to prevent cracking of thick and irregular sections.

(2) Thorough and uniform heating through sections to the correct hardening temperature.

(3) Control of furnace atmosphere, in the case of certain steel parts, to prevent scaling and decarburization.

(4) Correct heat capacity, viscosity, and temperature of quenching media, to harden adequately and to avoid cracks.

d. When heating steel, the temperature should be determined by the use of accurate instruments. At times, however, such instruments are not available, and in such cases the temperature of the steel may



be judged approximately by its color. The temperatures corresponding to various colors are given in table I; however, the accuracy with which temperatures may be judged by color depends on the experience of the workman and on the light in which the work is being done.

TABLE I.—Color chart for steel at various temperatures

| Color                   | ° F.   | Color               | ° F.   |
|-------------------------|--------|---------------------|--------|
| Faint red.....          | 900    | Salmon.....         | 1, 650 |
| Blood red.....          | 1, 050 | Orange.....         | 1, 725 |
| Dark cherry.....        | 1, 075 | Lemon.....          | 1, 825 |
| Medium cherry.....      | 1, 250 | Light yellow.....   | 1, 975 |
| Cherry or full red..... | 1, 375 | White.....          | 2, 200 |
| Bright red.....         | 1, 550 | Dazzling white..... | 2, 350 |

e. A number of liquids may be used for quenching steel. Both the media and the form of the bath depends largely on the nature of the work to be cooled. It is important that a sufficient quantity of the media be provided to allow the metal to be quenched without causing an appreciable change in the temperature of the bath. This is particularly important where many articles are to be quenched in succession.

(1) *Quenching procedure.*—The tendency of steel to warp and crack during the quenching process is difficult to overcome, and is due to the fact that certain parts of the article cool more rapidly than others. Whenever the transformation of temperature is not uniform, internal strains are set up in the metal which result in warpage or cracking, depending on the severity of the strains. Irregularly shaped parts are particularly susceptible to these conditions although parts of even section are often affected in a similar manner. Operations such as forging and machining may set up internal strains in steel parts and it is therefore advisable to normalize articles before attempting the hardening process. The following recommendations will greatly reduce the warping tendency and should be carefully observed:

(a) An article should never be thrown into the bath. By permitting it to lie on the bottom of the bath it is apt to cool faster on the top side than on the bottom side, thus causing it to warp or crack.

(b) The article should be slightly agitated in the bath to destroy the coating of vapor, which might prevent it from cooling rapidly. This allows the bath to rapidly convey its heat to the atmosphere.

(c) An article should be quenched in such a manner that all parts will be cooled uniformly and with the least possible distortion. For example, a gear wheel or shaft should be quenched in a vertical position.

(d) Irregularly shaped section should be immersed in such a manner that the parts of the greatest section enter the bath first.

(2) *Quenching media.*—(a) Water is used more than any other medium in the quenching of steel during the hardening process. The water bath should be maintained at 70° F., as extremely cold water is apt to warp or crack the steel, and water above this temperature will not produce the required hardness.

(b) Salt brine is used where higher heating capacity is necessary. The mixture is made by dissolving ordinary salt in water until a 10 percent solution is obtained.

(c) Oil is much slower in action than water and the tendency of heated steel to warp or crack when quenched may be greatly reduced by its use. Unfortunately, parts made from high carbon steel will not develop maximum hardness when quenched in oil unless they are quite thin in cross section. Its use is, however, recommended in all cases where it will produce the desired degree of hardness.

(d) For many articles such as milling cutters and similar tools, a bath of water covered by a film of oil is occasionally used. When the steel is plunged through this oil film a thin coating will adhere to it, retarding the cooling action of the water slightly, thus reducing the tendency to crack, due to contraction.

(3) *Straightening of parts warped in quenching.*—Warped parts must be straightened by heating first, and then applying pressure. This pressure should be gradual and must continue until the piece is cooled. If the article is not too large in cross section it may be placed between the centers of a lathe, then heated by some means until lard oil, applied to the surface, begins to smoke. At this point, pressure should be applied to the convex side by means of a tool shank held in the tool post. The pressure should be sufficient to spring the part slightly in the opposite direction from which it is bent. An article thus straightened may be cooled by applying wet cloths uniformly to the entire surface, or left between the centers until cooled by air. No attempt should be made to spring hardened steel without heating, regardless of the number of times it has been previously heated, as steel in its hardened condition cannot be bent or sprung cold with any degree of safety.

**7. Tempering.**—a. Steel in the hardened state may be considered in an unstable condition at atmospheric temperature. Tempering of

hardened steel is, in reality, a transformation of the unstable condition, known as martensite, to a more stable form. Hardened steel becomes fully transformed or reaches a stable condition at approximately 1,100° F. This transformation results in the formation of troostite and sorbite as the temperature increases. At approximately 400° F., martensite, which is the structure of properly hardened steel, begins to transform into troostite and at 750° F., troostite gradually changes into sorbite. At 1,100°, the transformation of troostite into sorbite is complete and the formative stage of pearlite begins. Pearlite is obtained by slow cooling from the critical point as in annealing.

b. Steel that has been hardened by rapid cooling from a point slightly above its critical range is often harder than necessary, and generally too brittle for most purposes. In addition, it is under severe internal strain. In order to relieve the strains and reduce the brittleness, the metal is usually "tempered." This is accomplished in the same types of furnaces as are used for hardening and annealing. However, less refined methods are sometimes used for tempering small tools.

c. As in the case of hardening, tempering temperatures may be approximately determined by color. These colors appear only on the surface and are due to a thin film of oxide which forms on the metal after the temperature reaches 450° F. In order to see the tempering colors, the surface must be brightened and a buff stick consisting of a piece of wood with emery cloth attached is ordinarily used for this purpose. When tempering by the color method, an open flame or heated iron plate is ordinarily used as the heating medium and, although the results are not absolutely accurate, it provides a very convenient means of tempering many small parts. The tempering temperatures and corresponding oxide colors are given in table II.

TABLE II.—Color chart for various tempering temperatures of carbon steels

| Oxide color                 | Metal temperature<br>(° F.) | Oxide color      | Metal temperature<br>(° F.) |
|-----------------------------|-----------------------------|------------------|-----------------------------|
| Pale yellow.....            | 428                         | Purple.....      | 531                         |
| Straw.....                  | 446                         | Dark blue.....   | 550                         |
| Golden yellow.....          | 469                         | Bright blue..... | 567                         |
| Brown.....                  | 491                         | Pale blue.....   | 610                         |
| Brown dappled with purple.. | 509                         |                  |                             |

**8. Annealing and normalizing.**—*a. Annealing.*—When steel is heated to a point above its critical range a condition referred to as

austenite is produced. If slowly cooled from above its critical temperature, the austenite is broken down and a succession of other conditions are produced, each being normal for a particular range of temperatures. Starting with austenite, these successive conditions are: martensite, troostite, sorbite, and finally pearlite.

(1) The most important step in annealing is to raise the temperature of the metal to the critical point, as any hardness that may have existed will then be completely removed. Strains which may have been set up through heat treatment will be eliminated when the steel is heated to the critical point and then restored to its lowest hardness by slow cooling. In annealing, the steel must never be heated more than 50° to 75° F. above the critical point and when large articles are annealed, sufficient time must be allowed for the heat to penetrate the metal.

(2) Steel is usually subjected to the annealing process for the following purposes:

- (a) To increase its ductility by reducing hardness and brittleness.
- (b) To refine the crystalline structure and remove stresses.

Steel which has been cold worked is usually annealed so as to increase its ductility. However, a large amount of cold-drawn wire is used in its cold-worked state when very high yield point and tensile strength are desired and relatively low ductility is permissible, as in spring wires, piano wires, wires for ropes, cables, etc. Heating to low temperatures, as in soldering, will destroy these properties unless done quickly.

(3) Assuming that the part to be annealed is heated to the proper temperature, the required slow cooling may be accomplished in several ways, depending on the metal and the degree of softness required: The common methods are packing and furnace cooling. Packing requires that the part be buried in some substance that does not conduct heat readily. For this purpose, a metal box containing slaked lime, ashes, or powdered charcoal is satisfactory, and care must be taken to keep the material perfectly dry. In furnace cooling, the part is merely left to cool down with the furnace.

b. Normalizing, although involving a slightly different heat treatment, may be classed as a form of annealing. This process removes all strains due to machining, forging, bending, and welding. Normalizing can only be accomplished with a good furnace, where the temperatures and the atmosphere may be closely regulated and held constant throughout the entire operation. A reducing atmosphere will normalize the metal with a minimum amount of oxide scale, while an oxidizing atmosphere will leave the metal heavily coated with

scale, thus preventing outside hardness in any subsequent hardening operation. The articles are put in the furnace and heated to a point above the critical temperature of the steel. After the parts have been held at this temperature for a sufficient time to allow the heat to penetrate to the center of the section, they must be removed from the furnace and cooled in still air. Drafts will result in uneven cooling, which will again set up strains in the metal. Prolonged soaking of the metal at high temperatures must be avoided, as this practice will cause the grain structure to enlarge. The length of time required for the soaking temperature will depend upon the mass of metal being treated.

**9. Case hardening.**—In many instances, it is desirable to produce a hard wear-resistant surface or “case” over a strong tough core. Treatment of this kind is known as “case hardening.” This treatment may be accomplished in several ways, the principal ways being carburizing, cyaniding, and nitriding.

*a. Carburizing.*—When steel is heated, the pores of the metal expand allowing it to absorb any gases to which it is exposed. By heating steel while in contact with a carbonaceous substance, carbonic gases given off by this material will penetrate the steel to an amount proportional to the time and temperature. For example, if mild or soft steel is heated to 1,350° F. in an atmosphere of carbonic gases, it will absorb the gas until approximately 0.50 percent of carbon content has been attained at the surface; this being the saturation point of the steel for the particular temperature. By increasing the heat to 1,650° F., the same steel will absorb the gas until a 1.50 percent carbon content has been attained, which is the normal saturation point for the increased temperature.

(1) The carburizing process may be applied to both plain carbon and alloy steels provided they fall within the low carbon range. Specifically, the carburizing steels are those containing not more than 0.20 percent carbon and are listed in table III. The lower the carbon content in the steel, the more readily it will absorb carbon during the carburizing process.

(2) The amount of carbon absorbed and the thickness of the case obtained increases with time; however, carburization progresses more slowly as the carbon content increases during the process. The length of time required to produce the desired degree of carburization and depth of case depends upon the composition of the metal, the kind of carburization material used, and the temperature to which the metal is subjected. It is apparent that in carburizing, carbon travels slowly from the outside toward the center and therefore, the propor-

tion of carbon absorbed must decrease from the outside to the center.

(3) Solid, liquid, and gas carburizing methods are employed.

(a) The simplest method of carburizing consists of soaking the parts at an elevated temperature while in contact with solid carbonaceous material such as wood charcoal, bone charcoal, charred leather, etc.

(b) Liquid carburizing consists of immersing the parts in a liquid salt bath heated to the proper temperature to which amorphous carbon has been added. The carbon penetrates the pores of the steel as in the solid method, producing the desired case.

(c) Gas carburizing consists of heating the parts in a retort and subjecting them to a carbonaceous gas such as carbon monoxide, or the common fuel gases. This process is particularly adaptable to certain engine parts.

(4) When carburizing, the parts are packed with the carburizing material in a sealed steel container to prevent the solid carburizing compound from burning and retain the carbon monoxide and dioxide gases. Nichrome boxes, capped pipes of mild steel, or welded mild steel boxes may be used. The former are most economical for production because they withstand oxidation. The latter two are useful only as substitutes. The container should be so placed as to allow the heat to circulate *entirely* around it. The furnace must be brought to the carburizing temperature as quickly as possible and held at this heat for from 1 to 16 hours depending upon the depth of case desired and the size of the work. After carburizing, the container should be removed and allowed to cool in air or the parts removed from the carburizing compound and quenched in oil or water. The air cooling, although slow, reduces warpage and is advisable in many cases. Carburizing temperatures for the various steels are given in table III.

(5) Carburized steel parts are rarely used without subsequent heat treatment, which consists of several steps to obtain optimum hardness in the case, and optimum strength and ductility in the core. Grain size of the core and case is refined.

(a) Refining the core is accomplished by reheating the parts to a point just above the critical temperature of the steel. After soaking for a sufficient time to insure uniform heating, the parts are quenched in oil. The temperatures required are given in table III.

(b) The hardening temperature for the high carbon case is well below that of the core. It is, therefore, necessary to again heat the parts to the critical temperature of the case and quench them in oil to produce the required hardness. A soaking period of 10 minutes is

generally sufficient. The temperatures required for this treatment are listed in table III.

(c) A final tempering operation is necessary to relieve the hardening strains produced by the previous treatments. This is accomplished by heating to the temperatures specified in table III, soaking until uniformly heated, and cooling in still air. When extreme hardness is desired the temperature should be carefully held to the lower limit of the range.

TABLE III.—*Carburizing heat treatment for steels*

| SAE steel | Carburizing temperature (° F.) <sup>1</sup> | Grain refinement temperature core <sup>2</sup> | Hardening temperature case <sup>3</sup> | Tempering or drawing temperature (° F.) |
|-----------|---------------------------------------------|------------------------------------------------|-----------------------------------------|-----------------------------------------|
| 1020----- | ° 1, 650 to 1, 700                          | 1, 575 to 1, 625                               | ° 1, 400 to 1, 425                      | 350 to 400                              |
| 2320----- | ° 1, 600 to 1, 650                          | 1, 500 to 1, 550                               | ° 1, 350 to 1, 400                      | 350 to 400                              |
| 2512----- | ° 1, 600 to 1, 650                          | 1, 450 to 1, 500                               | ° 1, 300 to 1, 350                      | 300 to 350                              |
| 3312----- | ° 1, 600 to 1, 650                          | 1, 425 to 1, 475                               | ° 1, 350 to 1, 400                      | 300 to 350                              |
| 4615----- | ° 1, 650 to 1, 700                          | 1, 450 to 1, 500                               | ° 1, 335 to 1, 400                      | 300 to 400                              |
| 6115----- | ° 1, 625 to 1, 675                          | 1, 550 to 1, 600                               | ° 1, 450 to 1, 500                      | 350 to 400                              |

<sup>1</sup> Carburize to desired depth of case, including allowance for grinding.

• Cool in air or quench in oil.

° Cool in box to 1,000° to 1,100° F. and then in air.

<sup>2</sup> Quench in oil. This treatment may be omitted for 1020 steel on low stressed parts.

<sup>3</sup> Quench.

• Water or brine.

° Oil.

*b. Cyaniding.*—Steel parts may be surface hardened by heating while in contact with a cyanide salt, followed by quenching. Only a thin case is obtained by this method and it is, therefore, seldom used in connection with airplane construction or repair. Cyaniding is, however, a rapid and economical method of case hardening and may be used in some instances for relatively unimportant parts. The work to be hardened should first be heated to 750° F., then immersed in a bath of molten sodium or potassium cyanide from 10 to 15 minutes. The cyanide bath should be maintained at a temperature of 1,550° to 1,600° F. Immediately after removal from the bath the parts are quenched in water. The case obtained in this manner is due principally to the formation of carbides on the surface of the steel. The use of a closed pot is required for cyaniding as cyanide vapors are extremely poisonous.

*c. Nitriding.*—(1) This method of case hardening is advantageous due to the fact that a harder case is obtained than by carburizing. Many engine parts such as cylinder barrels, gears, etc., may be treated

TABLE IV.—Composition of steels used in aircraft construction

| SAE number | Composition (percent) |                |                |                       |                   |                |                |                |                |                            |
|------------|-----------------------|----------------|----------------|-----------------------|-------------------|----------------|----------------|----------------|----------------|----------------------------|
|            | Carbon                | Silicon        | Manganese      | Phosphorous (maximum) | Sulphur (maximum) | Chromium       | Nickel         | Molybdenum     | Vanadium       | Other (maximum)            |
| 1025----   | 0. 20 to 0. 30        | -----          | 0. 50 to 0. 80 | 0. 045                | 0. 050            | -----          | -----          | -----          | -----          | -----                      |
| 1035----   | . 30 to . 40          | 0. 15 to 0. 35 | . 50 to . 80   | . 045                 | . 050             | -----          | -----          | -----          | -----          | -----                      |
| 1045----   | . 40 to . 50          | . 15 to . 35   | . 50 to . 80   | . 045                 | . 050             | -----          | -----          | -----          | -----          | -----                      |
| 1095----   | . 90 to 1. 05         | . 15 to . 35   | . 25 to . 50   | . 040                 | . 050             | -----          | -----          | -----          | -----          | -----                      |
| 2330----   | . 25 to . 35          | . 15 to . 30   | . 50 to . 80   | . 040                 | . 050             | -----          | 3. 25 to 3. 75 | -----          | -----          | -----                      |
| X-4130--   | . 25 to . 35          | . 15 to . 30   | . 50 to . 80   | . 040                 | . 050             | 0. 80 to 1. 10 | -----          | 0. 15 to 0. 25 | -----          | -----                      |
| X-4135--   | . 32 to . 39          | -----          | . 40 to . 60   | . 040                 | . 045             | . 80 to 1. 10  | -----          | . 15 to . 25   | -----          | -----                      |
| 4140----   | . 35 to . 45          | . 15 to . 30   | . 50 to . 80   | . 040                 | . 050             | . 80 to 1. 10  | -----          | . 15 to . 25   | -----          | -----                      |
| 3140----   | . 35 to . 45          | . 15 to . 30   | . 50 to . 80   | . 040                 | . 050             | . 45 to . 75   | 1. 00 to 1. 50 | -----          | -----          | -----                      |
| 3250----   | . 45 to . 55          | -----          | . 30 to . 60   | . 040                 | . 050             | . 90 to 1. 25  | 1. 50 to 2. 00 | -----          | -----          | -----                      |
| X-4340--   | . 35 to . 42          | -----          | . 60 to . 90   | . 025                 | . 025             | . 60 to . 80   | 1. 50 to 2. 00 | . 30 to . 40   | -----          | -----                      |
| Nitralloy  | . 38 to . 45          | . 30           | . 40 to . 70   | . 040                 | . 040             | 1. 40 to 1. 80 | . 30 to . 50   | -----          | -----          | -----                      |
| 4615----   | . 10 to . 20          | -----          | . 40 to . 70   | . 040                 | . 050             | -----          | 1. 65 to 2. 00 | . 20 to . 30   | -----          | -----                      |
| 6135----   | . 30 to . 40          | . 15 to . 30   | . 50 to . 80   | . 040                 | . 045             | . 80 to 1. 10  | -----          | 0. 15 to 0. 20 | 0. 15 to 0. 20 | -----                      |
| 6150----   | . 45 to . 55          | . 15 to . 30   | . 60 to . 90   | . 040                 | . 045             | . 80 to 1. 10  | -----          | . 15 to . 20   | . 15 to . 20   | -----                      |
| 6195----   | . 90 to 1. 05         | . 15 to . 30   | . 20 to . 45   | . 030                 | . 035             | . 80 to 1. 10  | -----          | . 15 to . 20   | . 15 to . 20   | -----                      |
| 51210----  | . 06 to . 13          | . 10 to . 50   | . 10 to . 55   | . 030                 | . 040             | 11. 5 to 13. 0 | . 10 to . 50   | -----          | -----          | Cu. 1.50                   |
| 51235----  | . 30 to . 40          | . 50 (max.)    | . 50 (max.)    | . 035                 | . 035             | 11. 5 to 14. 0 | -----          | -----          | -----          | Aluminum<br>0. 95 to 1. 35 |



in this way. Nitriding can only be applied to certain special steel alloys, one of the essential constituents of which is aluminum. The process involves the soaking of the parts in the presence of anhydrous ammonia at a temperature below the critical point of the steel. During the soaking period, the aluminum and iron combine with the nitrogen of the ammonia to produce iron nitrides in the surface of the metal. Warpage of work during nitriding can be reduced by stress relief annealing previously, and by exposure to nitrogen at temperatures no higher than 1,000° F. Growth of the work is similarly prevented, but cannot be entirely eliminated, and some parts may require special allowance in some dimensions to take care of growth. Nitralloy is a typical nitriding steel, the composition of which is given in table IV.

(2) The temperature required for nitriding is 950° F. and the soaking period from 48 to 72 hours. An airtight container must be used and should be provided with a fan to produce good circulation and even temperature throughout. No quenching is required and the parts may be allowed to cool in air.

## SECTION IV

### SPECIFIC HEAT TREATMENTS FOR AIRCRAFT STEELS

|                                                      | Paragraph |
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| High carbon chrome-molybdenum steel (SAE 4140).....  | 17        |
| Chrome-nickel steel (SAE 3140).....                  | 18        |
| Chrome-nickel steel (SAE 3250).....                  | 19        |
| Chrome-nickel-molybdenum steel (SAE X-4340).....     | 20        |
| Chrome-nickel steel (SAE 3435).....                  | 21        |
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| Medium carbon chrome-vanadium steel (SAE 6150).....  | 23        |
| High carbon chrome-vanadium steel (SAE 6195).....    | 24        |
| Chromium steel (SAE 51210).....                      | 25        |
| Chromium steel (SAE 51235).....                      | 26        |

**10. General.**—Each grade of steel possesses different hardening qualities which are governed by its composition. The various heat-treating operations for the commonly used aircraft steels are outlined in the following paragraphs (the composition of these steels is given in table IV). The holding or soaking period required during the hard-

ening operation represents a variable factor in each case, and may be approximated by reference to table V.

TABLE V.—*Soaking period for steels*

| Thickness of largest section of unit (inches) | Approximate weight unit (pounds) | Approximate time of heating (hours) | Approximate time of holding (hours) |
|-----------------------------------------------|----------------------------------|-------------------------------------|-------------------------------------|
| ¼ to 1.....                                   | Up to 100.....                   | ¾                                   | ½                                   |
| 1 to 2.....                                   | 100 to 300.....                  | 1¼                                  | ½                                   |
| 2 to 3.....                                   | 300 to 500.....                  | 1¾                                  | ¾                                   |
| 3 to 4.....                                   | 500 to 1,000.....                | 2¼                                  | 1                                   |
| 4 to 5.....                                   | 1,000 to 1,500.....              | 2¾                                  | 1                                   |
| 5 to 8.....                                   | 1,500 to 2,000.....              | 3½                                  | 1½                                  |

**11. Mild carbon steel (SAE 1025).**—Mild carbon steel is used extensively in the untreated condition for minor forgings and low stressed fittings. This steel responds to heat treatments in thin sections satisfactorily. The only physical property appreciably affected in heavier sections by heat treatment is toughness. This steel responds *readily to heat treatment*.

*a. Annealing.*—Annealing and normalizing require a temperature of between 1,575° and 1,650° F. The furnace should be brought to not more than 1,100° F. before the parts are inserted, then increased gradually to the annealing heat. Holding at this temperature should be continued for from 20 to 45 minutes depending upon the mass of the parts. After the heating operation, the parts are removed from the furnace and allowed to cool in still air.

*b. Hardening.*—The hardening temperature for mild steel is from 1,575° to 1,650° F. Upon removal from the furnace, the parts should be quenched in water or brine at 65° F. The ultimate tensile strength for this material is 55,000 pounds per square inch.

*c. Tempering.*—Mild carbon steel, or steel containing less than 0.30 percent carbon, does not harden sufficiently to require tempering except for thin sections.

**12. Medium carbon steel (SAE 1035).**—Medium carbon steel possesses good machining properties but is suitable for many small and medium size forgings where moderate physical properties are desired. This material is often referred to as structural steel.

*a. Annealing.*—The annealing and normalizing procedure for medium carbon steel is practically the same as that for mild steel. The upper limit of the annealing temperature in this case, however, may be as high as 1,675° F.

*b. Hardening.*—The hardening temperature for this steel is from 1,525° to 1,575° F. The steel should be placed in the furnace and gradually brought to the hardening heat. Parts exceeding  $\frac{3}{8}$  inch in thickness must be quenched in water, while all thinner sections may be quenched in a light oil, to avoid cracks due to contraction.

*c. Tempering.*—Medium carbon steel may be tempered by gradual reheating as required, until a temperature of 400° to 800° F. is reached. After holding the parts at this heat for a minimum of 45 minutes, they should be removed from the furnace and allowed to cool in still air. By proper tempering, an ultimate strength of approximately 100,000 pounds per square inch may be obtained.

**13. Medium carbon steel (SAE 1045).**—This grade of steel is treated in a manner similar to that employed for 1035 steel. Due to the higher carbon content however, the temperatures are somewhat different.

*a. Annealing.*—The annealing temperature range for this steel is between 1,475° and 1,650° F. while treatment is identical with that prescribed for 1035 steel.

*b. Hardening.*—The hardening temperature for this steel is from 1,475° to 1,525° F., and the hardening operation is performed in the same manner as described for 1035 steel.

*c. Tempering.*—This grade of steel is tempered at 400° to 950° F. as required, and cooled in still air. An ultimate tensile strength of approximately 110,000 pounds per square inch may be obtained by proper tempering.

**14. High carbon steel (SAE 1095).**—High carbon steel is used chiefly for hand and machine tools.

*a. Annealing.*—The annealing and normalizing temperature for high carbon steel is from 1,475° to 1,550° F. The procedure is similar to that employed for the other carbon steels and cooling should be accomplished in still air.

*b. Hardening.*—Maximum hardness is obtained by heating to a temperature of between 1,400° and 1,450° F., followed by a water quench. Due to the extreme brittleness resulting from this procedure, structural parts and springs should be hardened by heating to a temperature of from 1,500° to 1,550° F., and quenched in oil.

*c. Tempering.*—The stresses set up by quenching from the hardening temperature may be removed by tempering at 450° to 800° F. The maximum strength obtainable by tempering may be as high as 220,000 pounds per square inch.

**15. Nickel steel (SAE 2330).**—Nickel steel is intended for heat-treated parts such as bolts, nuts, etc., where considerable strength and toughness is desired.

*a. Annealing.*—Nickel steel may be annealed or normalized by heating to a temperature of from 1,500° to 1,600° F. and cooling in still air.

*b. Hardening.*—In hardening nickel steel, the furnace temperature should not exceed 1,100° F. when the parts are inserted; the temperature must then be gradually increased to from 1,430° to 1,500° F. This steel should be quenched in oil.

*c. Tempering.*—Tempering for aircraft requirements may be accomplished at any of three different temperatures, each producing a different ultimate strength. Regardless of the temperature used, the parts should be held at the temperature indicated for at least 30 minutes, then removed, and allowed to cool in still air.

| <i>Tempering temperature</i><br>(° F.) | <i>Ultimate strength</i><br>(pounds per square inch) |
|----------------------------------------|------------------------------------------------------|
| 1,050-----                             | 100,000                                              |
| 950-----                               | 125,000                                              |
| 800-----                               | 150,000                                              |

**16. Chrome-molybdenum steel (SAE X-4130 and X-4135).—**Chrome-molybdenum steel is used extensively in aircraft construction for tubular members, fittings, etc. It has excellent welding properties as well as high strength and toughness.

*a. Annealing and normalizing.*—For annealing, the temperature of the furnace should be held below 1,100° F. when the parts are inserted, then gradually increased to between 1,600° and 1,700° F. After holding the parts at this temperature for a sufficient time to allow full penetration of heat, the furnace should be shut down and the parts allowed to cool to 1,100° F. At this temperature, they should be removed, and allowed to cool in still air. The ultimate strength of the fully annealed steel is approximately 78,000 pounds per square inch. In normalizing, the parts are heated as described above, but removed from the furnace directly after the “soaking” period, and allowed to cool in still air. The ultimate strength obtained in this case is approximately 90,000 pounds per square inch.

*b. Hardening.*—Hardening is accomplished by inserting the parts in the furnace which has been preheated to not more than 1,100° F. After insertion, the temperature should be gradually increased to between 1,550° and 1,650° F. Parts having a thickness of less than ¼ inch should be heated to the lower limit of the range. After the soaking period the parts should be removed and quenched in oil.

*c. Tempering.*—Hardened parts may be tempered for various ultimate strengths. In any case, the furnace temperature should be below that of the tempering temperature when the parts are inserted,

then gradually brought to the required heat. In all cases, cooling is accomplished in still air.

| <i>Tempering temperature</i><br>(° F.) | <i>Ultimate strength</i><br>(pounds per square inch) |
|----------------------------------------|------------------------------------------------------|
| 1,075-----                             | 125, 000                                             |
| 1,000-----                             | 150, 000                                             |
| 950-----                               | 180, 000                                             |
| 650-----                               | 200, 000                                             |

**17. High carbon chrome-molybdenum steel (SAE 4140).—**Due to higher carbon content, this steel responds more readily to heat treatment than X-4130 steel. It is used extensively for heavy parts, machined from bar or forging stock. The heat-treatment procedure for this steel is identical with that described for X-4130 with the exception of the temperatures used.

*a. Annealing and normalizing* are accomplished at a temperature of between 1,600° and 1,700° F.

*b. Hardening* is accomplished at a temperature of from 1,525° to 1,625° F.

*c. Tempering* for aircraft requirements may be accomplished at any of three different temperatures, each producing a different ultimate strength.

| <i>Tempering temperature</i><br>(° F.) | <i>Ultimate strength</i><br>(pounds per square inch) |
|----------------------------------------|------------------------------------------------------|
| 1,250-----                             | 100, 000                                             |
| 1,100-----                             | 125, 000                                             |
| 650-----                               | 200, 000                                             |

**18. Chrome-nickel steel (SAE 3140).—**This steel may be used for heat-treated forgings that require greater strength and toughness than are obtainable with the plain carbon steels. Examples of its use may be found in connecting rods, crankshafts, etc.

*a. Annealing.*—Both annealing and normalizing may be accomplished by slow heating to between 1,550° and 1,650° F. In normalizing, cooling should be done in air after the required soaking.

*b. Hardening.*—After inserting the parts in the furnace at a temperature of 1,100° F. or less, the heat should be gradually increased between 1,475° and 1,525° F., which is the required hardening temperature. After the soaking period the parts should be removed from the furnace and quenched in oil.

*c. Tempering.*—The ultimate strength produced by tempering depends upon the temperature used. The furnace temperature prior to the insertion of the parts should be well below the tempering temperature.

| <i>Tempering temperature</i><br>(° F.) | <i>Ultimate strength</i><br>(pounds per square inch) |
|----------------------------------------|------------------------------------------------------|
| 1,050-----                             | 100,000                                              |
| 950-----                               | 150,000                                              |
| 800-----                               | 180,000                                              |

**19. Chrome-nickel steel (SAE 3250).**—This grade of steel is used for oil-hardened parts requiring high physical properties that are to be machined and forged.

*a. Annealing and normalizing.*—The annealing and normalizing temperature for this steel is between 1,500° and 1,600° F. and the heating procedure is similar to that described for 3140 steel. After heating, the parts should be left in the furnace and allowed to cool with it, if maximum softness is desired. When air-cooled from the normalizing temperature an ultimate strength of 90,000 pounds per square inch is obtained.

*b. Hardening.*—Gradual heating must be employed in the hardening procedure; the hardening temperature being between 1,425° and 1,475° F. After the soaking period the parts should be quenched in oil.

*c. Tempering.*—The ultimate strength of this steel depends upon the tempering temperature. Three tempering temperatures and the corresponding strength values follow:

| <i>Tempering temperature</i><br>(° F.) | <i>Ultimate strength</i><br>(pounds per square inch) |
|----------------------------------------|------------------------------------------------------|
| 1,100-----                             | 150,000                                              |
| 950-----                               | 180,000                                              |
| 800-----                               | 200,000                                              |

**20. Chrome-nickel-molybdenum steel (SAE X-4340).**—This steel has very good physical characteristics, making it satisfactory for parts, such as propeller hubs, and crankshafts, that are subjected to severe fatigue stresses.

*a. Annealing and normalizing.*—Annealing and normalizing may be accomplished by heating the steel to a temperature of between 1,500° and 1,600° F. The procedure is practically the same as that described for 3250 steel and includes furnace cooling.

*b. Hardening.*—Hardening is accomplished by gradual heating between 1,475° and 1,525° F., followed by a soaking period, depending on the size of the parts. After heating, the parts must be quenched in oil.

*c. Tempering.*—After quenching, the parts may be tempered for the various ultimate strengths indicated, by reheating to the following temperatures. (Quenching from the tempering heats must be accomplished in oil.)

| <i>Tempering temperature</i><br>(° F.) | <i>Ultimate strength</i><br>(pounds per square inch) |
|----------------------------------------|------------------------------------------------------|
| 1,200-----                             | 125, 000                                             |
| 1,050-----                             | 150, 000                                             |
| 950-----                               | 180, 000                                             |
| 850-----                               | 200, 000                                             |

**21. Chrome-nickel steel (SAE 3435).**—This steel is used for structural purposes in some instances and responds readily to heat treatment to produce a high strength material.

*a. Annealing and normalizing.*—The annealing and normalizing temperature for this steel is from 1,550° to 1,650° F. The procedure is the same as that described for 3250 steel and includes furnace cooling.

*b. Hardening.*—Hardening is accomplished by gradual heating to from 1,400° to 1,450° F., followed by an oil quench.

*c. Tempering.*—After hardening, the steel may be tempered as follows: (Quenching should be accomplished in still air.)

| <i>Tempering temperature</i><br>(° F.) | <i>Ultimate strength</i><br>(pounds per square inch) |
|----------------------------------------|------------------------------------------------------|
| 1, 000-----                            | 150, 000                                             |
| 900-----                               | 180, 000                                             |
| 800-----                               | 200, 000                                             |

**22. Medium carbon chrome-vanadium steel (SAE 6135).**—This material is a high strength steel used extensively for forged parts, such as crankshafts, connecting rods, etc.

*a. Annealing and normalizing.*—The annealing and normalizing temperature for this steel is from 1,600° to 1,700° F., and heating must be followed by air cooling.

*b. Hardening.*—This steel should be placed in the furnace and gradually brought to a temperature of between 1,575° and 1,625° F. After a sufficient soaking period the parts are quenched in oil.

*c. Tempering.*—Hardened parts may be tempered at the following temperatures to produce the corresponding ultimate tensile strength. In each case, cooling from the tempering temperature must be accomplished in still air.

| <i>Tempering temperature</i><br>(° F.) | <i>Ultimate strength</i><br>(pounds per square inch) |
|----------------------------------------|------------------------------------------------------|
| 950-----                               | 150, 000                                             |
| 800-----                               | 180, 000                                             |
| 750-----                               | 200, 000                                             |

**23. Medium carbon chrome-vanadium steel (SAE 6150).—**

This grade of steel is used to some extent in the manufacture of springs and also has a limited application for structural purposes, such as the manufacture of heat-treated forgings and machinable parts.

*a. Annealing and normalizing.*—Annealing and normalizing may be accomplished at the same temperature and in the same manner as described for 6135 steel. When this steel is air-cooled from the normalizing temperature, an ultimate strength of approximately 90,000 pounds per square inch is produced.

*b. Hardening.*—The hardening of this steel is accomplished at the same temperatures and in the same manner as described for 6135 steel.

*c. Tempering.*—The tempering of this steel is accomplished in the same manner as described for 6135 steel although the tempering heats must each be raised 50°, due to the higher carbon content.

**24. High carbon chrome-vanadium steel (SAE 6195).—**This steel is used for parts subjected to high bearing loads and requiring extreme hardness. Ball and roller bearings are examples of its use.

*a. Annealing and normalizing.*—Annealing and normalizing may be accomplished by slowly heating the steel to a temperature between 1,650° and 1,750° F., followed by furnace cooling.

*b. Hardening.*—Hardening is accomplished by gradual heating to between 1,425° and 1,475° F., followed by an oil quench.

*c. Tempering.*—The only tempering procedure applicable to this steel is accomplished by slowly heating the parts to 450° F. to remove quenching stresses.

**25. Chromium steel (SAE 51210).—**The carbon and chromium content causes this steel to develop a high degree of hardness such as required for the races, balls and rollers of antifriction bearings.

*a. Annealing and normalizing.*—Annealing and normalizing are accomplished by gradual heating to a temperature of from 1,525° to 1,575° F., followed by furnace cooling.

*b. Hardening.*—Parts to be hardened must be slowly brought to a temperature of from 1,700° to 1,850° F. After holding at this heat for a sufficient time to insure penetration, the parts are quenched in oil. The low side of the hardening temperature range should be used for sheet stock 0.06 inches or less in thickness; an intermediate point in the range should be used for sheet and wire 0.125 inches in thickness and the upper limit of the range should be used for bars and forgings.



*c. Tempering.*—The soaking time required for this steel must be at least twice that of the structural steels. Tempering at the various heats indicated will produce the following strength values:

| <i>Tempering temperature</i><br>(° F.) | <i>Ultimate strength</i><br>(pounds per square inch) |
|----------------------------------------|------------------------------------------------------|
| 1,200-----                             | 100, 000                                             |
| 1,100-----                             | 125, 000                                             |
| 750 -----                              | 180, 000                                             |

**26. Chromium steel (SAE 51235).**—This steel is often referred to as stainless steel, and possesses very high corrosive resistant qualities. It is used in the manufacture of such parts as pump shafts, bomb shackles, etc.

*a. Annealing and normalizing.*—The annealing and normalizing temperature of this steel is from 1,575° to 1,625° F. and the heating operation must be followed by furnace cooling.

*b. Hardening.*—Hardening is accomplished by thoroughly heating the steel to from 1,800° to 1,850° F. followed by an oil quench.

*c. Tempering.*—By reheating the hardened parts to 1,070° F. and cooling them in still air the corrosion-resistant quality, which is seriously reduced during hardening, is restored. The ultimate tensile strength after tempering is approximately 200,000 pounds per square inch.

SECTION V

GENERAL HEAT TREATMENT OF ALUMINUM ALLOY

|                               | Paragraph |
|-------------------------------|-----------|
| General-----                  | 27        |
| Heat-treating procedure-----  | 28        |
| Heat treatment of rivets----- | 29        |

**27. General.**—Commercially pure aluminum is very light but has no great amount of strength. It is, however, very valuable in the construction of many nonstructural units. In order to increase the strength of aluminum it is alloyed with various other metals to form the so-called “strong alloys” for structural use.

*a. Aluminum alloys* are available in both the wrought and cast form.

(1) A system of symbols has been standardized to designate the various wrought alloys. In this system a figure is used to indicate the composition of the material and is directly followed by the letter “S,” denoting the fact that the material is in the wrought form. Any of the following symbols may then be appended:

*O* = Dead soft or fully annealed.

*H* = Fully cold-worked or hard-wrought.

*W* = Condition after solution treatment and before aging.

*T* = Fully heat-treated and aged condition.

*RT* = Temper resulting from cold working after heat treatment and aging.

*A*, *B*, or *C* preceding the figure indicates a modification of the alloy.

(2) Cast aluminum alloys are represented by numbers and letters which are divided into two parts, separated by a hyphen. The first part of this identification symbol represents the composition as in the case of the wrought alloys, while the second part represents the condition of temper.

b. (1) Several of the aluminum alloys respond readily to heat treatment. In general, this treatment consists of heating the alloy to a known temperature, holding this temperature for a definite time, then quenching the part to room temperature or below. During the heating process a greater number of the constituents of the metal are put into solid solution. Rapid quenching retains this condition which results in a considerable improvement in the strength characteristics.

(2) The heating of aluminum alloy should be done in an electric furnace or molten salt bath. The salt bath generally used is a mixture of equal parts of potassium nitrate and sodium nitrate. Parts heated by this method must be thoroughly cleansed after treatment by washing in warm water, followed by rinsing in two baths of cold water. The temperature of the warm water must be held below 150° F., to prevent reduction of the corrosion resistance of the material. The salt bath method of heating should never be used for complicated parts and assemblies that cannot be easily washed free of the solution.

**28. Heat-treating procedure.—a. Types.**—Two types of heat treatment are applicable to aluminum alloys: the “solution” treatment and the “precipitation” treatment. Certain alloys develop their full strength from the solution treatment while others require both treatments for maximum strength.

(1) The solution treatment consists of heating the metal to the temperature required to cause the constituents to go into solid solution, holding or soaking the parts at this temperature for a sufficient time to complete the solution, followed by rapid quenching in cold water to retain the condition. The time of transfer from the furnace to the quench tank must not exceed seven seconds.

(2) The precipitation treatment consists of "aging" the parts previously subjected to the solution treatment at a definite temperature for a considerable time. During the aging period a portion of the alloying constituents precipitate out in the form of extremely fine particles, greatly increasing the strength of the alloy.

*b. Effects.*—Heat treatment affects not only the mechanical properties but also the corrosion-resistant properties. It is possible to obtain the desired mechanical properties upon heat treatment and yet fail to secure a maximum corrosion resistance by cooling too slowly. As little as 10° under the specified solution temperature may affect either the mechanical or corrosion-resistant properties or both.

*c. Quenching and aging.*—Quenching from the elevated temperature causes some increase in strength and hardness but the maximum values are not immediately obtained and the ductility is hardly affected. While in this condition the alloy will stand a considerable amount of cold forming without danger of rupture. After a period of approximately 1 hour the effects of aging begin to reduce the ductility of the material, making it impractical to work the alloy. Aging is a natural characteristic of the metal and is dependent on time and temperature. At temperatures below 32° F., aging is greatly retarded and the material may be held in a workable condition for several days by means of refrigeration. At room temperature, however, the aging effect will start at once and continue over a period of several days although it is practically complete in from 16 to 24 hours.

*d. Annealing.*—(1) The annealing procedure for aluminum alloys consists of bringing the alloys to an elevated temperature, holding or soaking them at this temperature for a length of time, depending upon the mass of the metal, then cooling them in still air. Annealing leaves the metal in the best condition for cold working; however, when prolonged forming operations are involved the metal will take on a condition known as "mechanical hardness" which will resist further working. In this case, it may be necessary to anneal the part several times during the forming process to avoid cracking. Aluminum alloy must not be used in the annealed state for highly stressed parts or fittings, and is rehardened for such application.

(2) Alclad parts should be heated as quickly and carefully as possible, due to the fact that long exposure to heat tends to cause some of the constituents of the core to diffuse into the pure aluminum coating, reducing the effectiveness of the pure aluminum as a corrosion-resistant material.

**29. Heat treatment of rivets.**—Rivets requiring heat treatment are usually heated in small screen wire baskets which allow free and rapid circulation of water during the quenching process. The time required for the rivets to reach the proper temperature will depend upon the relationship between the volume of the charge and the heating medium. The charge should be held at the specified temperature for not less than 30 minutes in a salt bath, or 1 hour in a still-air furnace, then quenched in the coldest water available. Rivets removed from the cold water and held at room temperature may be heated for a period of approximately 1 hour without cracking, and will harden completely in about 24 hours due to the effects of aging. Rivets made from 17S and 24S alloy must be heat-treated before use, whereas A17ST, 53S, 53SW, and 53ST rivets, may be driven in the condition in which they are received.

## SECTION VI

## SPECIFIC HEAT TREATMENTS FOR ALUMINUM ALLOYS

|                            | Paragraph |
|----------------------------|-----------|
| General .....              | 30        |
| Alloy 2S .....             | 31        |
| Alloy 3S .....             | 32        |
| Alloy 17S .....            | 33        |
| Alloy 17S Alclad .....     | 34        |
| Alloy 24S .....            | 35        |
| Alloy 24S Alclad .....     | 36        |
| Alloy 25S .....            | 37        |
| Alloy 51S .....            | 38        |
| Cast aluminum alloys ..... | 39        |

**30. General.**—Specific instruction for the heat treatment of the various aluminum alloys used in aircraft construction are given in paragraphs 31 to 39, inclusive. Although the general procedure remains the same, differences in composition demand that the factors such as time, temperature, etc., be held at a definite value for each case.

**31. Alloy 2S.**—*a. Composition.*—This material is referred to as commercially pure aluminum, being 99 percent aluminum and 1 percent impurities.

*b. Properties.*—The ultimate tensile strength is 15,000 pounds per square inch and the yield point 5,000 pounds per square inch when in the annealed condition.

*c. Uses.*—Fuel tanks, cowling, fairing, and other nonstructural parts are commonly made from this material.

*d. Heat treatment.*—Although not a heat-treatable alloy, this material may be annealed by heating to a temperature of between 625°

and 700° F., followed by quenching in still air. Hardening may only be accomplished by cold working.

**32. Alloy 3S.**—*a. Composition.*—This alloy consists of 97 percent aluminum, 1.2 percent manganese and the remainder impurities.

*b. Properties.*—The ultimate tensile strength is 19,000 pounds per square inch and the yield point 6,000 pounds per square inch for the material in the annealed condition.

*c. Uses.*—This alloy is used for the same purposes as 2S alloy.

*d. Heat treatment.*—This metal cannot be heat-treated for hardness. Annealing, to reduce hardness caused by cold working, may be accomplished by heating the parts to a temperature of from 725° to 775° F., followed by quenching in still air.

**33. Alloy 17S.**—*a. Composition.*—Alloy 17S is composed of 92 percent aluminum, 0.2 to 0.75 percent magnesium, 0.4 to 1.0 percent manganese and 3.5 to 4.5 percent copper.

*b. Properties.*—The ultimate tensile strength of this material is 26,000 pounds per square inch and the yield point 10,000 pounds per square inch when in the annealed condition. These values may be raised to 58,000 and 35,000, respectively, when in the heat-treated and aged condition and to 61,000 and 46,000, respectively, when cold-worked while in the heat-treated condition.

*c. Uses.*—This alloy is used extensively for stressed skin covering, extruded structural members, rivets, etc., and is available in sheet, tube, bar, and rod forms.

*d. Annealing.*—The annealing temperature is between 650° and 800° F., and quenching is accomplished in still air.

*e. Hardening.*—The hardening treatment is accomplished as follows:

- (1) Heat to 925°–950° F.
- (2) Hold at this temperature as prescribed in table VI.
- (3) Quench in cold water.
- (4) Age at room temperature for 24 hour for maximum hardness.

**34. Alloy 17S Alclad.**—*a. Composition.*—The composition of this material is identical with that of 17S alloy. The difference lies in the fact that the alloy has a thin coat of pure aluminum plated onto its surface to protect it from corrosion.

*b. Properties.*—The ultimate tensile strength of this material is 55,000 pounds per square inch and the yield point 32,000 pounds per square inch when in the heat-treated condition. These values may be raised to 57,000 and 40,000 pounds per square inch, respectively, by cold working after heat treatment.

*c. Uses.*—This material is particularly adaptable for use in exposed parts and surfaces, subject to corrosion.

*d. Annealing.*—The annealing temperature is between 640° and 660° F. and cooling from the annealing temperature is accomplished in still air.

*e. Hardening.*—The hardening treatment is identical with that described for alloy 17S.

**35. Alloy 24S.**—*a. Composition.*—This material is composed of 92 percent aluminum, 0.3 to 0.90 percent manganese, 1.25 to 1.75 percent magnesium, and 3.80 to 4.90 percent copper.

*b. Properties.*—The ultimate tensile strength of this material is 26,000 pounds per square inch and the yield point 10,000 pounds per square inch when in the annealed condition. These values raise to 65,000 and 43,000, respectively, when heat-treated for maximum hardness and to 68,000 and 53,000, respectively, when cold worked while in the heat-treated condition.

*c. Uses.*—This material is used in a similar manner to 17S alloy and is rapidly superseding it in many instances, due to its higher yield point.

*d. Annealing.*—The annealing temperature is between 650° and 800° F. and cooling is accomplished in still air.

*e. Hardening.*—The hardening treatment is accomplished as follows:

- (1) Heat to 915°–930° F.
- (2) Hold at this temperature as prescribed in table VI.
- (3) Quench in cold water.
- (4) Age at room temperature for 24 hours.

**36. Alloy 24S Alclad.**—*a. Composition.*—The composition of this alloy is identical with that of 24S alloy and, as in the case of 17S Alclad, the only difference lies in the protective coating of pure aluminum.

*b. Properties.*—The ultimate tensile strength of this material is 60,000 pounds per square inch and the yield point 40,000 pounds per square inch when in the heat-treated and aged condition. These values may be raised to 62,000 and 49,000, respectively, by cold working after heat treatment.

*c. Uses.*—As in the case of 17S alloy this material is used in assemblies subjected to corrosion.

*d. Annealing.*—The annealing temperature is from 640° to 660° F. and cooling is accomplished in still air.

*e. Hardening.*—The hardening treatment is identical with that described for alloy 24S.

**37. Alloy 25S.**—*a. Composition.*—This material is composed of 92 percent aluminum, 0.4 to 1.2 percent manganese, 0.02 percent (maximum) magnesium, 3.9 to 5.0 percent copper and 0.5 to 1.2 percent silicon.

*b. Properties.*—The ultimate strength of this material is 26,000 pounds per square inch and the yield point 10,000 pounds per square inch when in the annealed condition. These values may be raised to 48,000 and 25,000, respectively, by heat treating and aging at room temperature. Heat treatment followed by artificial aging again raises the values to a maximum of 58,000 and 35,000, respectively.

*c. Uses.*—This material in the forged and heat-treated condition is used extensively for propeller blades, connecting rods, bearing material, etc.

*d. Annealing.*—The annealing temperature is between 650° and 800° F. and cooling must be accomplished in still air.

*e. Hardening.*—The hardening treatment is accomplished as follows:

- (1) Heat to 960°–980° F.
- (2) Hold at this temperature as prescribed in table VI.
- (3) Quench in cold water.
- (4) Age artificially at a temperature between 285° and 315° F. for from 8 to 12 hours.

TABLE VI.—Soaking period for 17S, 17S Alclad, 24S, and 25S alloys

| Thickness of material (inches)         | Minimum time of soaking for solution treatment (hours) |           |
|----------------------------------------|--------------------------------------------------------|-----------|
|                                        | Air furnace                                            | Salt bath |
| Up to $\frac{1}{32}$ -----             | 10                                                     | 10        |
| $\frac{1}{32}$ to $\frac{1}{16}$ ----- | 20                                                     | 15        |
| $\frac{1}{16}$ to $\frac{1}{8}$ -----  | 30                                                     | 20        |
| $\frac{1}{8}$ to $\frac{3}{16}$ -----  | 40                                                     | 20        |
| $\frac{3}{16}$ to $\frac{1}{4}$ -----  | 60                                                     | 20        |
| $\frac{1}{4}$ to $\frac{1}{2}$ -----   | 90                                                     | 30        |

**38. Alloy 51S.**—*a. Composition.*—This alloy is composed of 96.5 percent aluminum, 0.2 percent (maximum) manganese, 0.45 to 0.8 percent magnesium, 0.15 to 0.35 percent chromium, 0.3 percent (maximum) copper, and 0.6 to 1.2 percent silicon.

*b. Properties.*—The ultimate strength of this material is 16,000 pounds per square inch and the yield point 5,500 pounds per square inch while in the annealed condition. These values are raised to 35,000 and 20,000, respectively, by heat treatment followed by aging at room temperature and may be further increased to 48,000 and 35,000, respectively, by artificial aging.

*c. Uses.*—As in the case of 25S alloy, this alloy is used principally in the forged form for various engine parts.

*d. Annealing.*—This alloy may be annealed by heating to a temperature of 650° F., followed by slow cooling in still air.

*e. Hardening.*—The hardening procedure is identical with that described for 25S alloy with the single exception that the artificial aging temperature must be increased to from 315° to 325° F.

**39. Cast aluminum alloys.**—The heat treatment of the various cast aluminum alloys used in aircraft construction is beyond the scope of this manual, due to the fact that this work is seldom required of a mechanic engaged in maintenance work. As a representative example, however, the treatment of cast alloy 142 is given below.

*a. Composition.*—This material is composed of 92 percent aluminum, 1.7 to 2.3 percent nickel, 1.2 to 1.8 percent magnesium, and 3.7 to 4.5 percent copper.

*b. Properties.*—The ultimate strength of this alloy is 28,000 pounds per square inch and the yield point 24,000 pounds per square inch.

*c. Uses.*—Pistons as well as various other engine parts may be made from this alloy.

*d. Heat treatment.*—Treatment for maximum strength is accomplished as follows:

- (1) Heat to 940°–960° F.
- (2) Hold at this temperature for 5 hours.
- (3) Quench in cold water.
- (4) Age at 350°–400° F., for 5 hours.

## SECTION VII

### HARDNESS TESTING

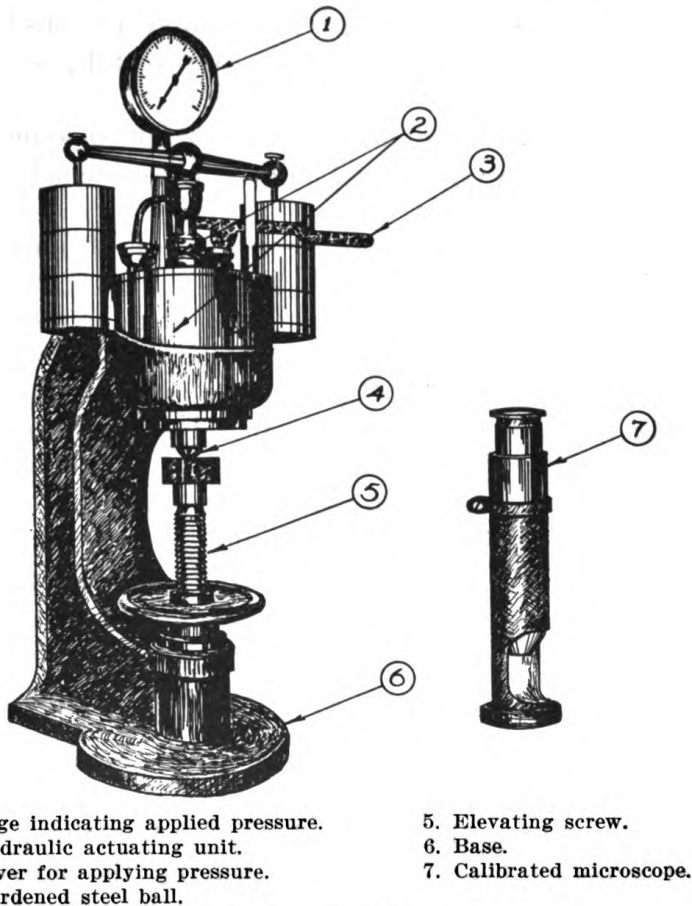
|                                       | Paragraph |
|---------------------------------------|-----------|
| General .....                         | 40        |
| Brinell hardness test .....           | 41        |
| Rockwell hardness test .....          | 42        |
| Shore scleroscope hardness test ..... | 43        |

**40. General.**—Hardness testing is an important factor in the determination of the results of heat treatment as well as the condition of the metal before heat treatment and must, therefore, be carefully considered in connection with this work. The figures shown in table VII represent a close approximation of the relation between the tensile strength and hardness of wrought carbon and low alloy steels only. This table is very useful for inspection of these materials but should not be used for other metals except in a very general manner. The methods of hardness testing in general use are: the Brinell, Rockwell, and Shore scleroscope, each of which is discussed in subsequent paragraphs.



**41. Brinell hardness test.**—*a.* This test consists of pressing a hardened steel ball into a flat surface of the metal being tested by the application of a known pressure. The impression made by the ball is measured by means of a microscope with a micrometer eyepiece, and the Brinell "number" is obtained by dividing the load in kilograms by the area of the spherical impression made by the ball, measured in square millimeters. The thickness of all samples used for testing must be sufficient to prevent bulging on the under side.

*b.* The Brinell tester (fig. 5) consists of the following major parts:



- |                                      |                           |
|--------------------------------------|---------------------------|
| 1. Gage indicating applied pressure. | 5. Elevating screw.       |
| 2. Hydraulic actuating unit.         | 6. Base.                  |
| 3. Lever for applying pressure.      | 7. Calibrated microscope. |
| 4. Hardened steel ball.              |                           |

FIGURE 5.—Brinell hardness tester.

(1) An elevating screw and anvil for bringing the sample into contact with the ball.

(2) A manually operated hydraulic pump for applying the pressure to the hardened steel ball, which is mounted on its actuating member.

(3) A pressure gage for determining the applied pressure.

(4) A release mechanism to relieve the hydraulic pressure after the test has been made.

(5) A microscope with micrometer eyepiece for calculating the area of the impression.

c. The test is performed as follows:

(1) Prepare the sample by filing, grinding, polishing, etc., to remove all scratches and variations that may effect the reading.

(2) Place the sample on the anvil of the machine and elevate until hardened ball contacts surface to be tested.

(3) Apply the load by pumping handle shown at (3), figure 5.

(a) A load of 3,000 kilograms is required for steel, while 500 kilograms is used when testing the softer metals, such as brass, bronze, etc.

(b) Normally, the load should be applied for 30 seconds although this period may be increased to 1 minute for extremely hard steels, in order to produce equilibrium.

(4) Release the pressure, and measure area of impression with calibrated microscope.

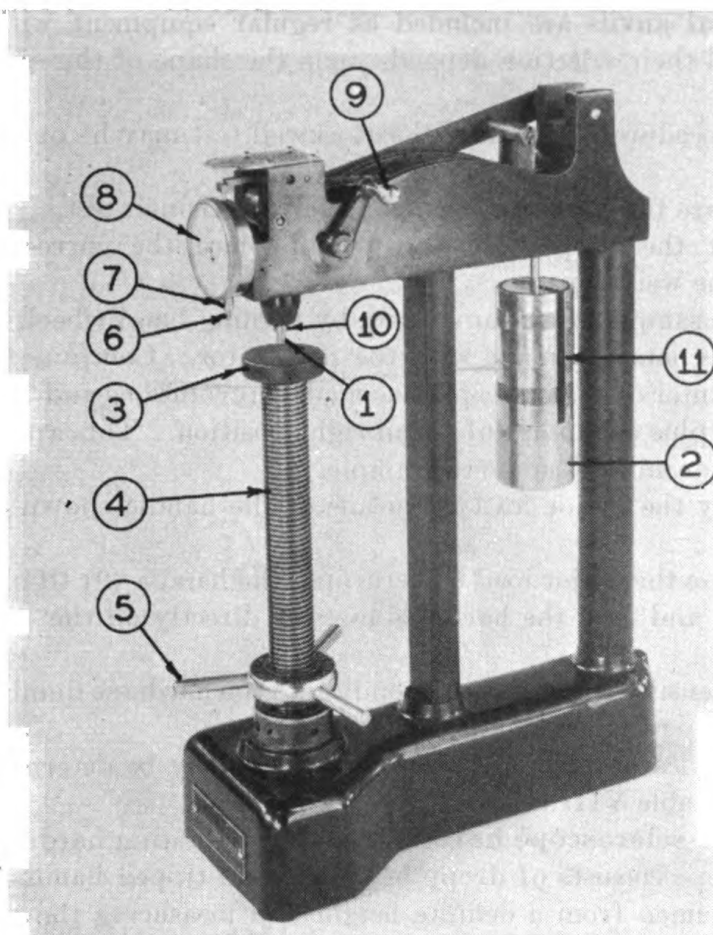
(5) Calculate the Brinell number, completing the test.

(a) After obtaining a Brinell number for a metal, its corresponding tensile strength may be determined by referring to table VII.

(b) Reference may also be made to table VIII to identify the metal and determine its heat treatment.

**42. Rockwell hardness test.**—a. The Rockwell hardness test consists of the measurement of the difference between a minor and major load applied to a diamond penetrator or hardened steel ball. In all tests, a minor load of 10 kilograms is first applied, in order to seat the penetrator in the surface of the specimen. The actual penetration is then produced by applying a major load. When using the diamond cone penetrator, this major load is 150 kilograms but when a  $\frac{1}{16}$ -inch steel ball is used the load is reduced to 100 kilograms. An indication of the application of the major load may be observed by watching the dial indicator; after the pointer comes to rest this major load is released, leaving the minor load still applied. As Rockwell hardness numbers are based on the difference between the depths of penetration at major and minor load, it will be evident that the greater this difference, the less the hardness number and the softer the material. This difference is automatically registered when the major load is released by a reversed scale on the indicator dial, which thus reads directly the Rockwell hardness number.

b. The machine (fig. 6) consists principally of a base, or standard, elevating screw, anvil, penetrator, device for applying the load, and dial indicator.



- |                          |                          |
|--------------------------|--------------------------|
| 1. Penetrator.           | 7. Gage sleeve.          |
| 2. Weight pan.           | 8. Indicating gage dial. |
| 3. Anvil.                | 9. Crank handle.         |
| 4. Elevating screw.      | 10. Plunger rod.         |
| 5. Hand wheel.           | 11. Major load.          |
| 6. Indicating gage stem. |                          |

FIGURE 6.—Rockwell hardness tester.

(1) The dial indicator is provided with two scales. The black or C scale and the red or B scale. The C scale is used when testing with the diamond cone and 150 kilogram load while the B scale is used in connection with the steel-ball penetrator and 100 kilogram load. Readings, when recorded, must be prefixed by the letter B or C to show which scale has been used and a column is provided for each scale in table VII. When the readings fall below the table value, C-20 (B-98),

the material is considered too soft for the diamond cone and a  $\frac{1}{16}$ -inch hardened ball should be used. The diamond cone must be used for all hard materials (those above 100 on the B scale) as the steel ball may be deformed by the test.

(2) Several anvils are included as regular equipment with each machine and their selection depends upon the shape of the section to be tested.

c. The procedure for making the Rockwell test may be outlined as follows:

(1) Prepare the sample as described for the Brinell test.

(2) Select the proper penetrator and place the corresponding weight on the weight pan.

(3) Place sample on the anvil and, by turning hand wheel, raise it slowly until contact is made with the penetrator. Continue turning until the pointer of the indicator has made 3 revolutions and is within 5 divisions (plus or minus) of the upright position. This applies the 10 kilogram or minor load on the sample.

(4) Apply the major load by means of the handle shown at (9), figure 6.

(5) Release the major load by returning the handle (9) to its original position and read the hardness number directly on the indicator scale.

(a) The tensile strength corresponding to the hardness number may be obtained by referring to table VII.

(b) Identification and condition of temper may be determined by reference to table VIII.

**43. Shore scleroscope hardness test.**—*a.* Testing hardness with the scleroscope consists of dropping a diamond-tipped hammer upon the test specimen from a definite height and measuring the rebound produced. In one type of tester, the height of the rebound must be measured directly on the scale of the machine, while on another the amount is indicated on a dial.

*b.* The tester (fig. 7) consists of the following major parts:

(1) A base, provided with leveling screws, and a clamping arrangement to hold the sample to be tested.

(2) A vertical glass tube, mounted to the base and containing the cylindrical diamond-point hammer.

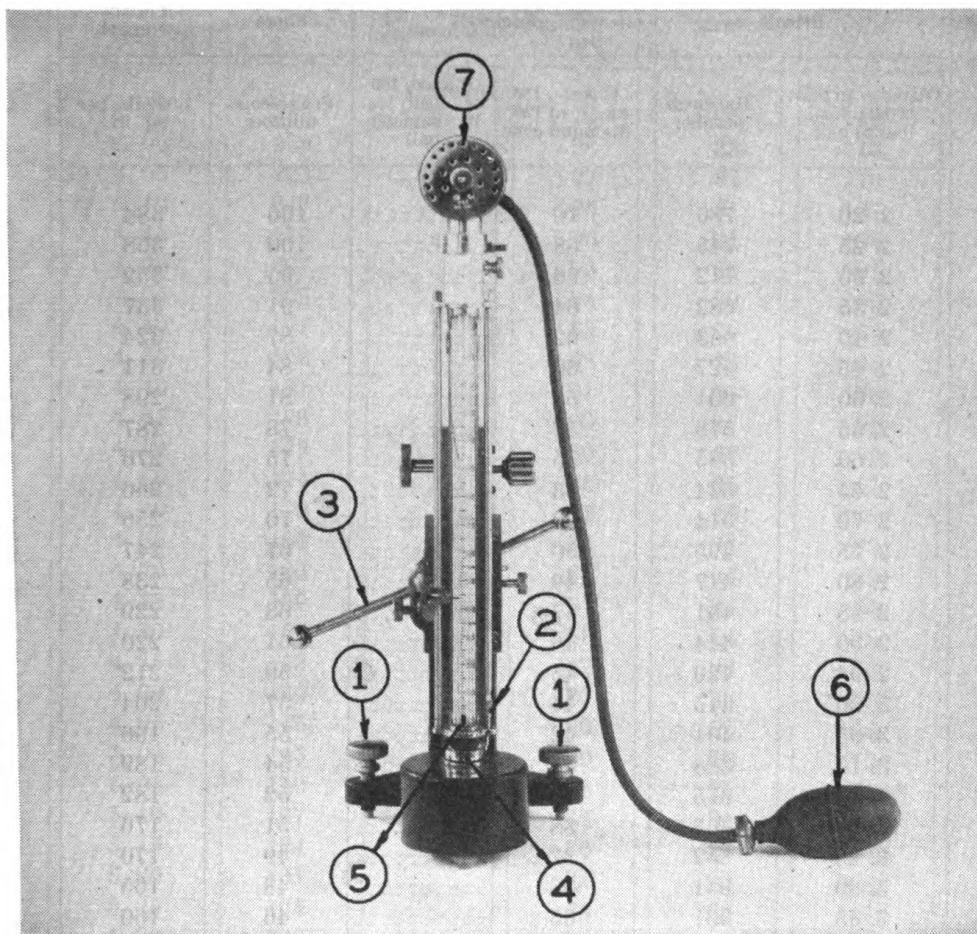
(3) A suction head and bulb for lifting and releasing the hammer.

(4) A scale, visible through the glass tube, for determining the height of the rebound.

(5) A magnifier hammer with a larger contact area is supplied for use with extremely soft metals.

c. The test is made as follows:

(1) Level the instrument by means of the adjusting screws shown at (1), figure 7. The level position is determined by means of the plumb rod shown at (2).



- |                    |                           |
|--------------------|---------------------------|
| 1. Tripod screws.  | 5. Diamond-tipped hammer. |
| 2. Plumb rod.      | 6. Release bulb.          |
| 3. Clamping lever. | 7. Head.                  |
| 4. Clamping shoe.  |                           |

FIGURE 7.—Shore scleroscope.

(2) Prepare test specimen as described for the Brinell and Rockwell tests and clamp it on the base. This is done by raising lever (3), inserting the sample, and exerting pressure on the clamping shoe (4).

(3) Raise the hammer (5) by squeezing and releasing the bulb (6).

(4) Release the hammer by again squeezing the bulb and observe its rebound.

(5) Several tests should be made at different points of a specimen, and an average reading taken to reduce visual error.

(6) The results obtained from the test may then be checked against the values given in tables VII and VIII.

TABLE VII.—*Approximate relations between hardness and tensile strength of SAE steels*<sup>1</sup>

| Brinell                                          |                    | Rockwell                                       |                                                          | Shore                 | Tensile strength         |
|--------------------------------------------------|--------------------|------------------------------------------------|----------------------------------------------------------|-----------------------|--------------------------|
| Diameter in mm.<br>3,000 kg. load,<br>10-mm ball | Hardness<br>number | C scale, 150<br>kg., load 120°<br>diamond cone | B scale, 100<br>kg., load, 1/16-<br>in. diameter<br>ball | Scleroscope<br>number | 1,000 lb. per<br>sq. in. |
| 2. 20                                            | 780                | 70                                             | -----                                                    | 106                   | 384                      |
| 2. 25                                            | 745                | 68                                             | -----                                                    | 100                   | 368                      |
| 2. 30                                            | 712                | 66                                             | -----                                                    | 95                    | 352                      |
| 2. 35                                            | 682                | 64                                             | -----                                                    | 91                    | 337                      |
| 2. 40                                            | 653                | 62                                             | -----                                                    | 87                    | 324                      |
| 2. 45                                            | 627                | 60                                             | -----                                                    | 84                    | 311                      |
| 2. 50                                            | 601                | 58                                             | -----                                                    | 81                    | 298                      |
| 2. 55                                            | 578                | 57                                             | -----                                                    | 78                    | 287                      |
| 2. 60                                            | 555                | 55                                             | -----                                                    | 75                    | 276                      |
| 2. 65                                            | 534                | 53                                             | -----                                                    | 72                    | 266                      |
| 2. 70                                            | 514                | 52                                             | -----                                                    | 70                    | 256                      |
| 2. 75                                            | 495                | 50                                             | -----                                                    | 67                    | 247                      |
| 2. 80                                            | 477                | 49                                             | -----                                                    | 65                    | 238                      |
| 2. 85                                            | 461                | 47                                             | -----                                                    | 63                    | 229                      |
| 2. 90                                            | 444                | 46                                             | -----                                                    | 61                    | 220                      |
| 2. 95                                            | 429                | 45                                             | -----                                                    | 59                    | 212                      |
| 3. 00                                            | 415                | 44                                             | -----                                                    | 57                    | 204                      |
| 3. 05                                            | 401                | 42                                             | -----                                                    | 55                    | 196                      |
| 3. 10                                            | 388                | 41                                             | -----                                                    | 54                    | 189                      |
| 3. 15                                            | 375                | 40                                             | -----                                                    | 52                    | 182                      |
| 3. 20                                            | 363                | 38                                             | -----                                                    | 51                    | 176                      |
| 3. 25                                            | 352                | 37                                             | -----                                                    | 49                    | 170                      |
| 3. 30                                            | 341                | 36                                             | -----                                                    | 48                    | 165                      |
| 3. 35                                            | 331                | 35                                             | -----                                                    | 46                    | 160                      |
| 3. 40                                            | 321                | 34                                             | -----                                                    | 45                    | 155                      |
| 3. 45                                            | 311                | 33                                             | -----                                                    | 44                    | 150                      |
| 3. 50                                            | 302                | 32                                             | -----                                                    | 43                    | 146                      |
| 3. 55                                            | 293                | 31                                             | -----                                                    | 42                    | 142                      |
| 3. 60                                            | 285                | 30                                             | -----                                                    | 40                    | 138                      |
| 3. 65                                            | 277                | 29                                             | -----                                                    | 39                    | 134                      |
| 3. 70                                            | 269                | 28                                             | -----                                                    | 38                    | 131                      |
| 3. 75                                            | 262                | 26                                             | -----                                                    | 37                    | 128                      |
| 3. 80                                            | 255                | 25                                             | -----                                                    | 37                    | 125                      |
| 3. 85                                            | 248                | 24                                             | -----                                                    | 36                    | 122                      |
| 3. 90                                            | 241                | 23                                             | 100                                                      | 35                    | 119                      |

<sup>1</sup> Emphasis is laid on the fact that this table gives an *approximate* relationship of Brinell, Rockwell, and Scleroscope values. It is impossible to give more than an approximate relationship due to the inevitable influence of size, mass, composition, and method of heat treatment. Where more precise factors are required they should be especially developed for each steel composition, heat treatment, and part. (Table VII was reproduced by permission of the Society of Automotive Engineers.)

TABLE VII.—*Approximate relations between hardness and tensile strength of SAE steels—Continued*

| Brinell                                          |                    | Rockwell                                       |                                                          | Shore                 | Tensile strength         |
|--------------------------------------------------|--------------------|------------------------------------------------|----------------------------------------------------------|-----------------------|--------------------------|
| Diameter in mm.<br>3,000 kg. load,<br>10-mm ball | Hardness<br>number | C scale, 150<br>kg., load 120°<br>diamond cone | B scale, 100<br>kg., load, 1/16-<br>in. diameter<br>ball | Scleroscope<br>number | 1,000 lb. per<br>sq. in. |
| 3.95                                             | 235                | 22                                             | 99                                                       | 34                    | 116                      |
| 4.00                                             | 229                | 21                                             | 98                                                       | 33                    | 113                      |
| 4.05                                             | 223                | 20                                             | 97                                                       | 32                    | 110                      |
| 4.10                                             | 217                | -----                                          | 96                                                       | 31                    | 107                      |
| 4.15                                             | 212                | -----                                          | 96                                                       | 31                    | 104                      |
| 4.20                                             | 207                | -----                                          | 95                                                       | 30                    | 101                      |
| 4.25                                             | 202                | -----                                          | 94                                                       | 30                    | 99                       |
| 4.30                                             | 197                | -----                                          | 93                                                       | 29                    | 97                       |
| 4.35                                             | 192                | -----                                          | 92                                                       | 28                    | 95                       |
| 4.40                                             | 187                | -----                                          | 91                                                       | 28                    | 93                       |
| 4.45                                             | 183                | -----                                          | 90                                                       | 27                    | 91                       |
| 4.50                                             | 179                | -----                                          | 89                                                       | 27                    | 89                       |
| 4.55                                             | 174                | -----                                          | 88                                                       | 26                    | 87                       |
| 4.60                                             | 170                | -----                                          | 87                                                       | 26                    | 85                       |
| 4.65                                             | 166                | -----                                          | 86                                                       | 25                    | 83                       |
| 4.70                                             | 163                | -----                                          | 85                                                       | 25                    | 82                       |
| 4.75                                             | 159                | -----                                          | 84                                                       | 24                    | 80                       |
| 4.80                                             | 156                | -----                                          | 83                                                       | 24                    | 78                       |
| 4.85                                             | 153                | -----                                          | 82                                                       | 23                    | 76                       |
| 4.90                                             | 149                | -----                                          | 81                                                       | 23                    | 75                       |
| 4.95                                             | 146                | -----                                          | 80                                                       | 22                    | 74                       |
| 5.00                                             | 143                | -----                                          | 79                                                       | 22                    | 72                       |
| 5.05                                             | 140                | -----                                          | 78                                                       | 21                    | 71                       |
| 5.10                                             | 137                | -----                                          | 77                                                       | 21                    | 70                       |
| 5.15                                             | 134                | -----                                          | 76                                                       | 21                    | 68                       |
| 5.20                                             | 131                | -----                                          | 74                                                       | 20                    | 66                       |
| 5.25                                             | 128                | -----                                          | 73                                                       | 20                    | 65                       |
| 5.30                                             | 126                | -----                                          | 72                                                       | -----                 | 64                       |
| 5.35                                             | 124                | -----                                          | 71                                                       | -----                 | 63                       |
| 5.40                                             | 121                | -----                                          | 70                                                       | -----                 | 62                       |
| 5.45                                             | 118                | -----                                          | 69                                                       | -----                 | 61                       |
| 5.50                                             | 116                | -----                                          | 68                                                       | -----                 | 60                       |
| 5.55                                             | 114                | -----                                          | 67                                                       | -----                 | 59                       |
| 5.60                                             | 112                | -----                                          | 66                                                       | -----                 | 58                       |
| 5.65                                             | 109                | -----                                          | 65                                                       | -----                 | 56                       |
| 5.70                                             | 107                | -----                                          | 64                                                       | -----                 | 55                       |
| 5.75                                             | 105                | -----                                          | 62                                                       | -----                 | 54                       |
| 5.80                                             | 103                | -----                                          | 61                                                       | -----                 | 53                       |
| 5.85                                             | 101                | -----                                          | 60                                                       | -----                 | 52                       |
| 5.90                                             | 99                 | -----                                          | 59                                                       | -----                 | 51                       |
| 5.95                                             | 97                 | -----                                          | 57                                                       | -----                 | 50                       |
| 6.00                                             | 95                 | -----                                          | 56                                                       | -----                 | 49                       |

TABLE VIII.—*Coordination of commercial metal designations and specification numbers*  
AIRCRAFT STEELS

| Material                              | Commercial designation | Specification number |                 |                                       | Final hardness (Brinell number) |                                          |
|---------------------------------------|------------------------|----------------------|-----------------|---------------------------------------|---------------------------------|------------------------------------------|
|                                       |                        | Bar and rod          | Sheet and strip | Tube                                  | Tempering temperature (° F.)    | Hardness number                          |
| Mild steel                            | SAE 1025               | QQ-S-646             | QQ-S-651        | WW-T-846                              | 1,150-1,200                     | 140 to 165                               |
| Medium carbon steel                   | SAE 1035               | 57-107-20            |                 |                                       | 950-975                         | 160 to 250                               |
| Do                                    | SAE 1045               | 57-107-15            |                 |                                       | 1,000                           | 193 to 259                               |
| High carbon steel                     | SAE 1095               | 57-107-14            |                 |                                       | 800-850                         | 400 to 430                               |
| Nickel steel                          | SAE 2330               | 57-107-17            |                 |                                       | 950                             | 250 to 300                               |
| Nickel-chromium steel                 | SAE 3250               | 57-107-6             |                 |                                       | 800                             | 310 to 360                               |
|                                       |                        |                      |                 |                                       | 800                             | 408                                      |
| Chrome-molybdenum steel               | SAE X-4130             | 57-107-19            | 57-136-8        | { Round 57-180-2<br>Streamline 57-183 | { 1,075<br>925<br>775           | { 250 to 300<br>310 to 360<br>360 to 400 |
| Do                                    | SAE X-4135             |                      |                 | 10,239                                | 625                             | 400 to 440                               |
| High carbon chrome-molybdenum steel   | SAE 4140               | 10083                |                 |                                       | 650                             | 408                                      |
| Chrome-nickel steel                   | SAE 3140               | 57-107-3             |                 |                                       | 1,050                           | 250 to 300                               |
|                                       |                        |                      |                 |                                       | 950                             | 310 to 360                               |
|                                       |                        |                      |                 |                                       | 800                             | 360 to 400                               |
| Chrome-nickel-molybdenum steel        | SAE X-4340             | 11062                |                 |                                       | 1,200                           | 250 to 300                               |
|                                       |                        |                      |                 |                                       | 1,050                           | 310 to 360                               |
|                                       |                        |                      |                 |                                       | 950                             | 360 to 400                               |
| Nickel-molybdenum steel (carburizing) | SAE 4615               | 10240                |                 |                                       | 850                             | 400 to 440                               |
| Medium carbon chrome-vanadium steel   | SAE 6135               | 57-107-16            | 57-136-8        |                                       | 275-350                         | 279 to 430                               |
|                                       |                        |                      |                 |                                       | 1,175                           | 250 to 300                               |
|                                       |                        |                      |                 |                                       | 1,025                           | 310 to 360                               |



|                                         |           |           |         |            |
|-----------------------------------------|-----------|-----------|---------|------------|
| High carbon chrome-vanadium steel.      | SAE 6150  | QQ-S-687  | 700-850 | 400 to 444 |
| Chrome-molybdenum-A1 steel (nitriding). | Nitralloy | 57-107-28 |         | 280 to 340 |
| Chrome-vanadium steel                   | SAE 6195  | 57-107-11 |         |            |
| Chromium steel                          | SAE 51210 | 10080     |         |            |
| Chromium steel                          | SAE 51235 | 57-107-13 |         |            |

## ALUMINUM ALLOYS

| Material                   | Commercial designation | Specification number                  |                 |          | Hardness (Brinell number) |                  |
|----------------------------|------------------------|---------------------------------------|-----------------|----------|---------------------------|------------------|
|                            |                        | Bar and rod                           | Sheet and strip | Tube     | Temper                    | Number           |
| Commercially pure aluminum | 2S                     | QQ-A-411                              | 57-151-1        | WW-T-783 | {O<br>H}                  | 23<br>44         |
| Aluminum alloy             | 3S                     | QQ-A-356                              | QQ-A-359        | WW-T-788 | {O<br>H}                  | 28<br>55         |
| Do                         | 17S                    | QQ-A-351                              | QQ-A-353        | WW-T-786 | {O<br>T<br>RT}            | 45<br>100<br>110 |
| Do                         | Alclad 17S             |                                       | 57-152-2        |          |                           |                  |
| Do                         | 24S                    | 11071                                 | 11066           | 10235    | {O<br>T<br>RT}            | 42<br>105<br>116 |
| Do                         | Alclad 24S             |                                       | 11067           |          |                           |                  |
| Do                         | 25S                    | Available only as forgings<br>57-153. |                 |          | {O<br>W<br>T}             | 45<br>80<br>100  |
| Do                         | 51S                    | Available only as forgings<br>57-153. |                 |          |                           | 90               |

## SECTION VIII

## MAGNAFLUX INSPECTION

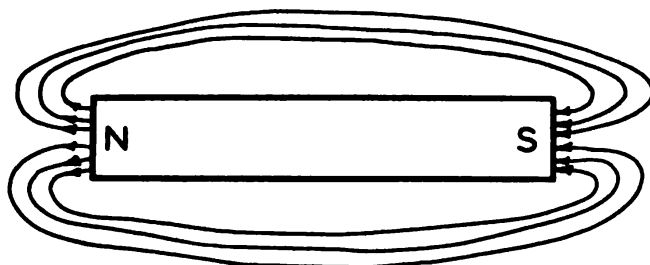
|                                         | Paragraph |
|-----------------------------------------|-----------|
| General.....                            | 44        |
| Principles of magnaflux inspection..... | 45        |
| Magnaflux testing equipment.....        | 46        |
| Magnetizing methods.....                | 47        |
| Application of magnaflux method.....    | 48        |
| Maintenance.....                        | 49        |

**44. General.**—*a.* In aircraft and engine assemblies embodying rapidly rotating, reciprocating, or vibrating parts, failures occur that are brought about by the presence of very small defects, not generally considered to be detrimental in other types of structures. The magnaflux method of inspection is a nondestructive test to reveal the presence of hidden cracks, seams, laps, slag inclusions, and similar defects in ferromagnetic materials such as iron and steel, which cannot be detected visually. Magnaflux inspection does not displace other non-destructive methods such as the X-ray and acid etching for the detection of such defects as porosity, gas pockets, and slag inclusions, in metal. However, for rapid and dependable detection, and definition of cracks and flaws in or near the surface of polished parts, the magnaflux method has proved most reliable.

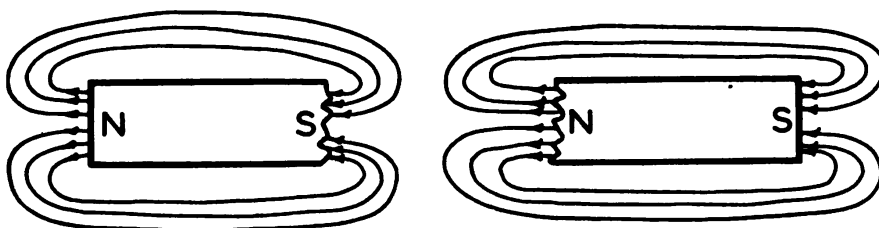
*b.* It must be remembered that the results obtained by magnaflux inspection are always relative and that many defects of little or no consequence will be found along with those of importance. The operator is constantly faced with the difficulty of deciding which defects are of consequence, which are to be disregarded as being of no significance, and which should be investigated further. It must be borne in mind that in case of doubt, it is better to reject the part than to take a chance on its soundness. At times, the indications formed on the work may be confusing, in that they seem to indicate the presence of defects where none exists. This condition is brought about by sharp changes in contour, such as splines, and keyways, and calls for considerable skill on the part of the operator for proper identification.

**45. Principles of magnaflux inspection.**—*a.* The basis of the magnaflux method of inspection lies in the fact that if a simple bar magnet (fig. 8 ①) is broken in two, opposite magnetic poles are immediately formed at the break as shown at ②. This fact remains true regardless of the number of times the magnet is broken and in effect results in the formation of a new bipolar magnet each time a break is made. Should the break instead of extending clear through the magnet result only in a crack, the above phenomena will again be

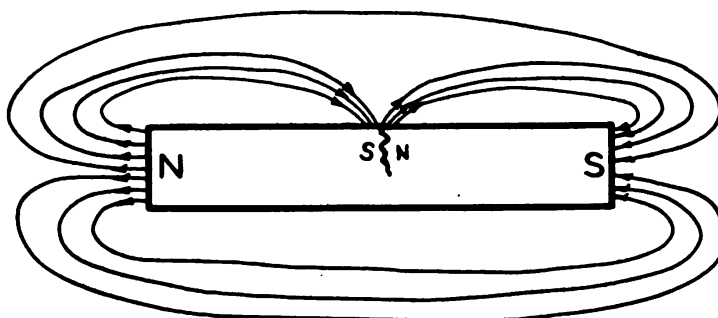
produced, and opposite poles will be formed on the two sides of the crack as shown at ③. In the conditions illustrated in ② and ③, the formation of new magnetic poles is caused either by a complete or partial break in the path of the magnetic flux. This fact may be assumed to include any discontinuity or abrupt change in the degree of ease with which the magnetic flux is allowed to flow.



① Field about a solid bar.



② Fields produced by breaking bar.



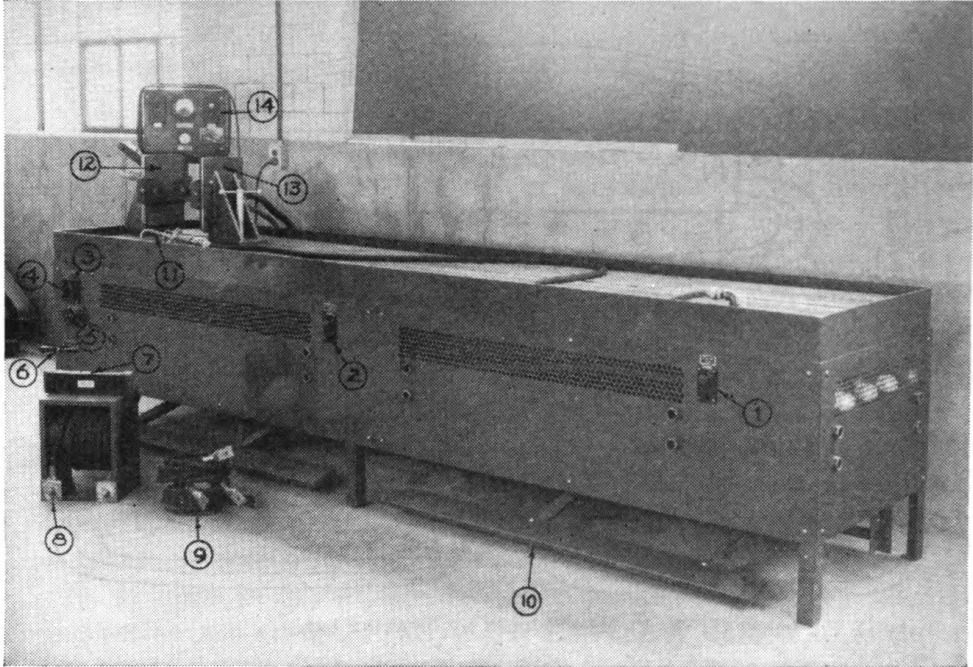
③ Field produced by a crack in bar.

FIGURE 8.—Magnetic field about a steel bar.

b. The presence of these magnetic discontinuities may be detected by the application of finely divided ferromagnetic particles. As the particles are brought in the vicinity of the flaw they offer a better path for the leaking magnetic flux and therefore tend to gather at the point of leakage, outlining its boundaries. The ferromagnetic particles may either be in the form of a dry powder or held in sus-

pension in a suitable liquid such as kerosene. The latter method is used throughout the Air Corps.

c. The materials that may be inspected by this method must be capable of being magnetized. Alloys of steel that are only faintly magnetic do not, as a rule, produce satisfactory results.



- |                                            |                               |
|--------------------------------------------|-------------------------------|
| 1, 2, and 3. Magnetizing current switches. | 9. Auxiliary flexible cable.  |
| 4. Pump motor switch.                      | 10. Treadle lock.             |
| 5. Current control rheostat.               | 11. Nozzle and hose assembly. |
| 6. Rheostat short circuit switch.          | 12. Fixed contact head.       |
| 7. Contact block.                          | 13. Movable contact head.     |
| 8. Bipolar coil.                           | 14. Indicator panel.          |

FIGURE 9.—Magnetizing unit.

**46. Magnaflux testing equipment.**—The equipment necessary for conducting an inspection consists of the following major parts:

a. *Magnetizing apparatus.*—This unit (fig. 9) provides the means for magnetizing the parts to be inspected, and may be operated by either direct or alternating current. The alternating current system is not, at present, being used in the Air Corps and will therefore not be described.

(1) The direct current magnetizer is supplied with current from storage batteries contained in the unit, and maintained in a charged condition by means of an integral battery charger. The magnetizing current is controlled by means of switches and a rheostat shown at the left of the illustration.

(2) The magnetizing current is supplied to the part to be inspected by means of the contact heads shown at (12) and (13), figure 9. The bipolar coil (8) may be used to produce a magnetic field around parts held between the contact blocks.

(3) The inspection medium is contained in a tank or sump and applied to the part being inspected by means of the hose and nozzle shown at (11). The excess fluid drains back to the sump from the grill top of the machine. Pressure is applied to the medium by means of a circulating pump contained in the sump. This pump also serves to keep the ferromagnetic particles well mixed in the liquid vehicle.

*b. Demagnetizing apparatus.*—After parts have been magnetically inspected, the magnetism must be removed in order to return them to their original condition. This operation is accomplished by passing the parts through an alternating current field. Two demagnetizing units are furnished as standard equipment with each magnaflux machine, giving a sufficient size range to accommodate practically any piece used in aircraft construction. These units are mounted side by side on suitable supports. In either case, the unit consists chiefly of an insulated coil of wire to which alternating current is connected through a suitable switch attached to the unit.

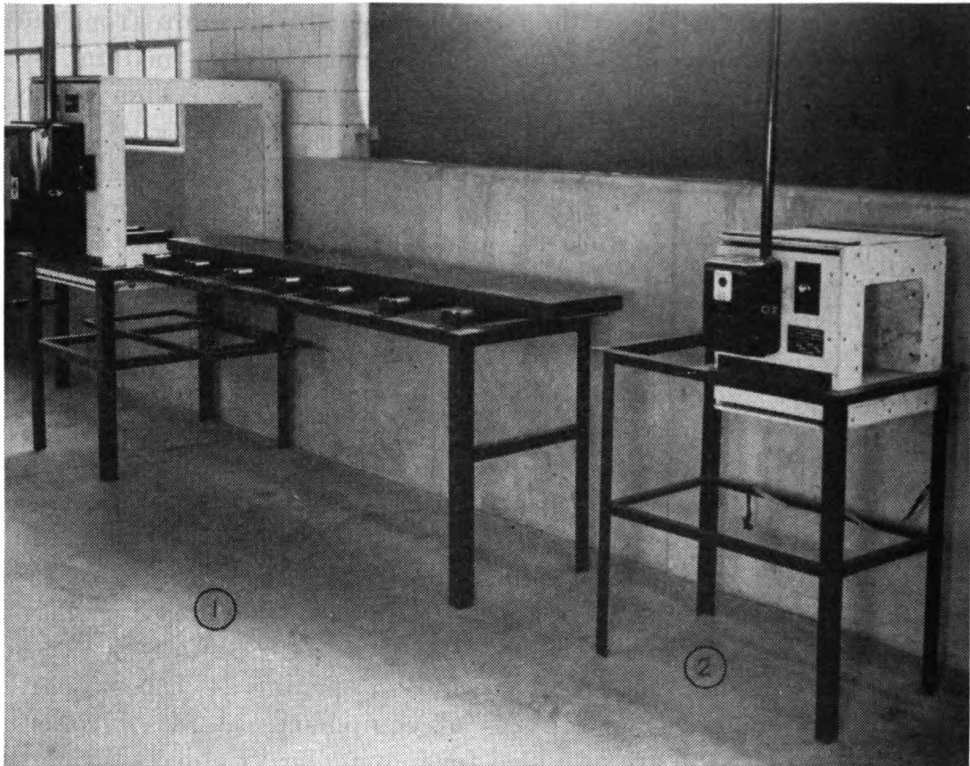
(1) The smaller of the two units, shown at (1) in figure 10, has an opening nine inches square and is particularly adapted for small engine and propeller parts.

(2) The large unit, shown at (2), has an opening 24 inches square and will accommodate large pieces of equipment. A set of rollers and movable platform are provided for moving heavy objects through the coil.

*c. Rinse tank.*—A rinse tank is usually provided for removing the inspection medium, after completion of the test. Any type of tank may be used for this purpose, provided it is of a size sufficient to allow "slushing" of the parts. The rinse bath may consist of clear-light oil or a mixture of equal parts of naphtha and carbon tetrachloride.

**47. Magnetizing methods.**—*a.* The effectiveness of magnaflux testing is lost unless certain basic principles regarding the direction of flow of the magnetic flux lines are observed. If the direction of the flux lines are parallel to the defect, only a small amount of the magnetic flux will be interrupted, with the result that there will be insufficient polarity developed to attract the ferromagnetic particles in sufficient quantities to indicate the defects. When the direction of the flux is at an angle of  $90^\circ$  to the length of the defect, the flux

will be interrupted and the strongest indication of a given defect will be shown. The failure to obtain flux lines other than parallel to the defects may result in failure to locate them. It follows, therefore, that parts should be magnetized in several directions and the powder applied after each magnetization, as a second magnetization



1. Large unit.

2. Small unit.

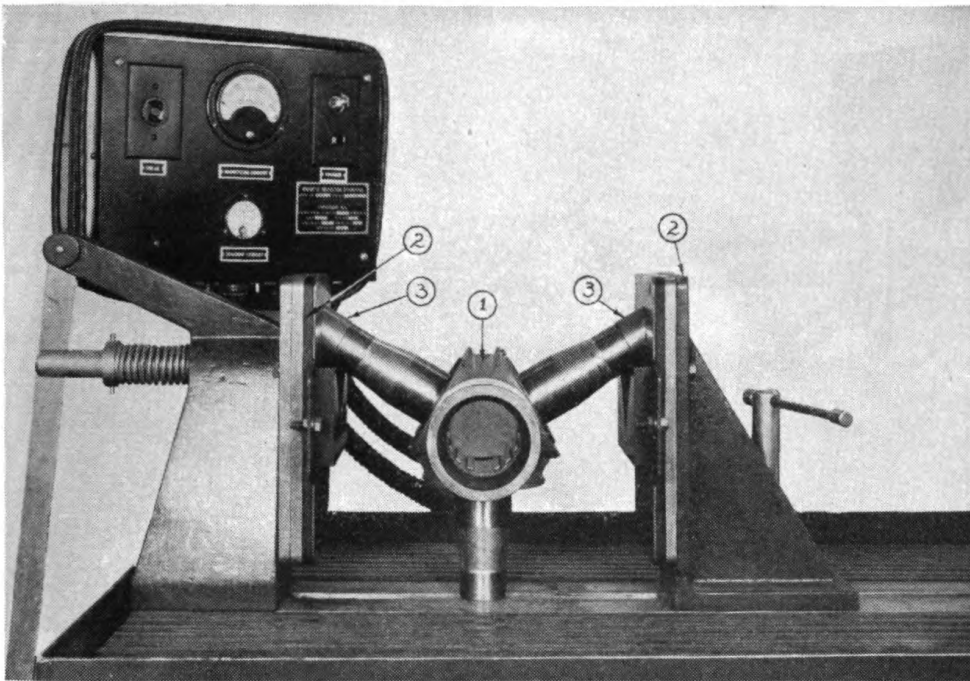
FIGURE 10.—Demagnetizing apparatus.

tends to neutralize the first. Parts to be inspected should be free of grease, loose grit, and dirt. Paint, lacquer, plating, and other protective coatings, if dry, need not be removed.

b. Magnetizing methods may be divided into two general groups: the residual method, and the continuous method.

(1) In the residual method of magnetization, the residual magnetism of the material being inspected is relied upon to attract the particles. The residual magnetism is imparted to the object by means of an initial charge induced by the magnetizing apparatus. This method is not considered as sensitive as the continuous method although it may be used to produce satisfactory results in many cases.

(2) In the continuous method, the magnetism is induced during the time the inspection medium is being applied, and continues for a sufficient period to allow the particles to orient themselves. As the flux leakage at any break in the magnetic field is proportional to the intensity of the magnetism, it may readily be seen that the results will be more pronounced than in the case of the residual method.



1. Spider being inspected.  
2. Contact heads.

3. Special contact blocks.

FIGURE 11.—Circular method of magnetization applied to a propeller hub spider.

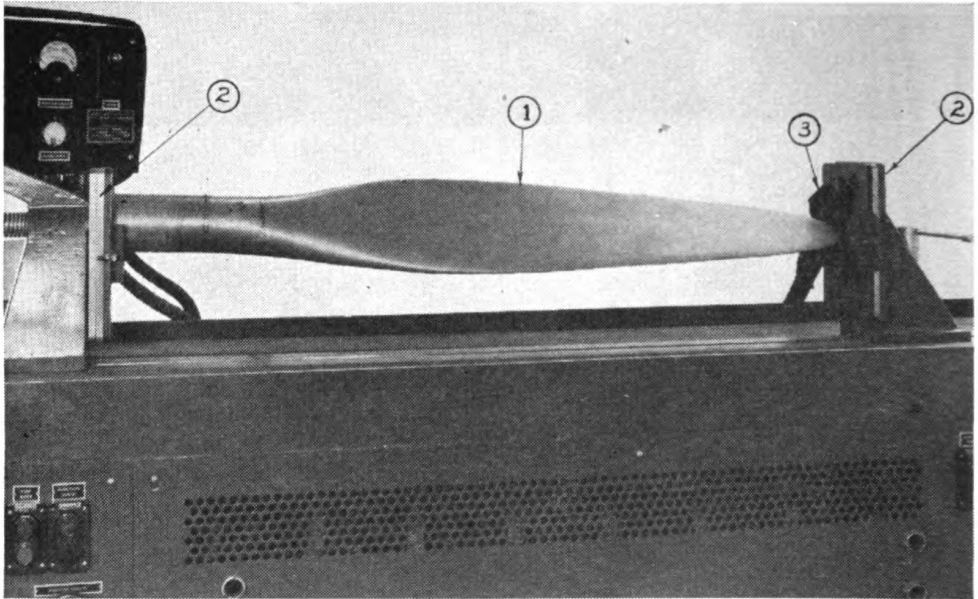
*c.* Regardless of whether the continuous or residual method is used, magnetism may be imparted in either of the following ways:

(1) When the part to be magnetized is placed between the contact heads of the machine and the magnetizing current is passed directly through it (figs. 11 and 12), a circular magnetic field is set up in and about the part and the operation is referred to as circular magnetization. This method is particularly advantageous as it will indicate practically any defect discoverable by magnaflux inspection; however, this should not be taken to mean that it is the only method to be used. Inasmuch as circular magnetization requires a current of low voltage but relatively high amperage, great care must be exercised to prevent burning, which may result from poor contact, dirty headplates, or too



high a current value for the area of contact. A heavy copper gauze, as shown in figure 10, or special contact blocks serve to increase the area of contact and reduce the danger.

(2) When the part is magnetized by placing it in a coil or solenoid, the operation is termed bipolar magnetization. In this method no current is passed through the part; the magnetism being induced by the current flow through the bipolar or solenoid coil. The magnetic lines



1. Blade being inspected.  
2. Contact heads.

3. Copper gauze for increasing contact area.

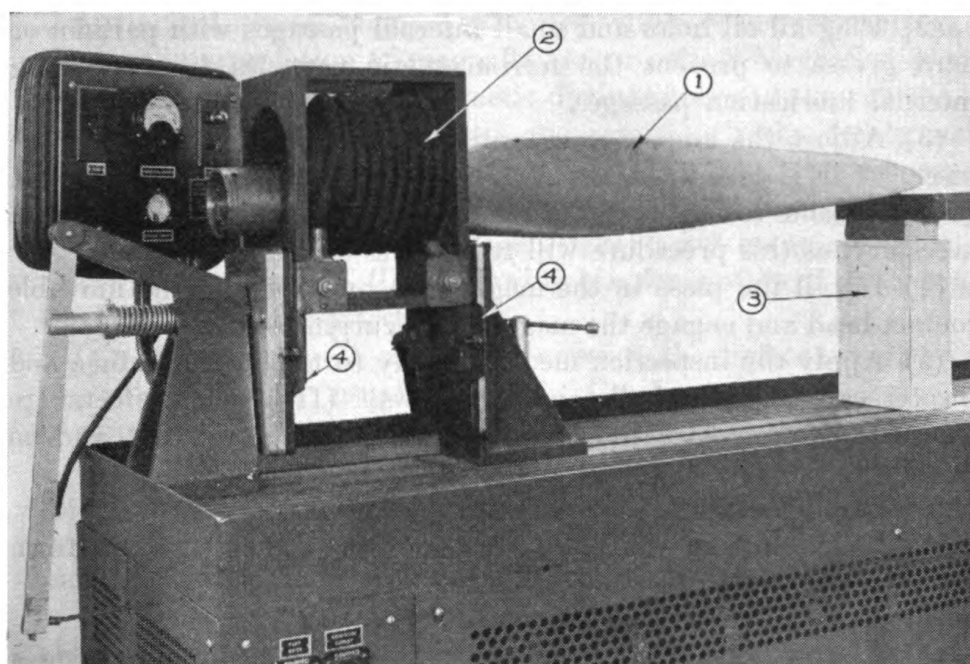
FIGURE 12.—Circular magnetization of a propeller blade.

of force are parallel to the axis of the piece, forming a magnetic field similar to that of a bar magnet. Whenever possible the bipolar coil assembly should be used (fig. 13). However, for parts too large to fit inside the bipolar coil assembly, a coil of 3 to 6 turns may be formed around the part by the use of the auxiliary cable (fig. 14). The terminals of this auxiliary cable are attached to the contact heads, and the test conducted in the same manner as when using the bipolar coil assembly.

**48. Application of magnaflux method.—a.** The following is an outline of the steps necessary in a complete inspection. Although not required in every case, both the circular and bipolar methods of magnetization are included in order to make the procedure complete.

(1) Clean the part thoroughly to insure freedom from grease, dirt, pencil marks, fingerprints, etc.

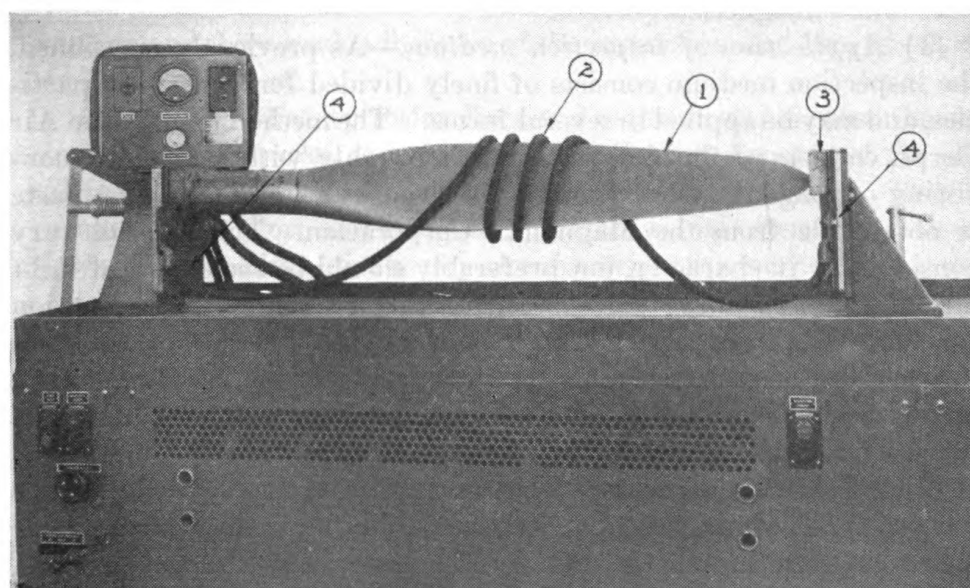




1. Blade being inspected.  
2. Bipolar coil.

3. Insulated support.  
4. Contact blocks.

FIGURE 13.—Magnetization of propeller blade using bipolar coil.



1. Propeller blade being inspected.  
2. Auxiliary coil.

3. Insulating spacer block.  
4. Contact heads.

FIGURE 14.—Bipolar magnetization by means of an auxiliary coil.

(2) Plug all oil holes and small internal passages with paraffin or hard grease to prevent the ferromagnetic particles from entering internal lubrication passages.

(3) Adjust the amperage according to the size and shape of the piece. This is done by means of the rheostat shown at (5) in figure 9. It is advisable to begin with a relatively low setting and raise it if necessary, as this procedure will reduce the danger of burning.

(4) Install the piece in the magnetizer by adjusting the movable contact head and engage the magnetizing current switch.

(5) Apply the inspection medium freely to the entire surface and inspect carefully for indications of flaws. (If serious defects are shown to be present at this time, the part should be rejected, and no further test is necessary.)

(6) Demagnetize the part in demagnetizing unit.

(7) Install bipolar coil and adjust movable contact head to form the necessary electrical contact (fig. 13).

(8) Engage magnetizing current switch.

(9) Remove bipolar coil, and apply inspection medium, making a final inspection for defects.

(10) Demagnetize part in demagnetizing unit.

(11) Remove inspection medium in rinse tank, completing the test.

b. The following is a detailed description of the various operations that follow magnetization:

(1) *Application of inspection medium.*—As previously mentioned, the inspection medium consists of finely divided ferromagnetic particles, and may be applied in several forms. The method used by the Air Corps, consists of flushing the part thoroughly with a mixture, consisting of magnaflux No. 7 paste dissolved in a light oil. The paste is obtainable from the Magnaflux Corporation. The oil can vary considerably in character, but preferably should be some type of light oil, or a dry cleaning solvent conforming to Federal Specification PS661a. Kerosene mixed with a light grade of engine oil makes a satisfactory substitute. Other products that can be used are varsol manufactured by the Standard Oil Company or ultrasine manufactured by the Atlantic Refining Company.

(2) *Evaluation of defects.*—Proficiency in the recognition of the various types of magnaflux indications, and ability to evaluate their significance by making a reliable estimate of the character, depth, and extent of the underlying discontinuities that cause them, can only be gained from practical experience. A fair knowledge of metallurgy, heat treatment of ferromagnetic materials, a conception of grain flow in the part, and of the location, direction, intensity, and character of

the principal stresses imposed in service, will be found very helpful for the best interpretation of magnaflux test results. Magnaflux powder collects along the lines of magnetic disturbances and thus defines the defects as to location, character, and extent. Cracks, faulty welds, seams, laps, cavities, inclusions, tool marks, and scratches, are among the most common defects that may be detected. Most magnaflux indications of any consequence are unmistakable but many are often the cause for speculation. The following is a description of these defects as they appear under test:

(a) *Open cracks*.—A crack that is open to the surface is well defined by a sharp line, usually jagged. Cracks resulting from heat treatment or fatigue are regularly open to the surface.

(b) *Hidden cracks*.—A crack that is not open to the surface is traced by a fuzzy line, the width increasing with its size and depth below the surface. Hidden cracks are developed in the processes of manufacture, such as forging, welding, and heat treating.

(c) *Grinding cracks*.—Grinding cracks appear in large numbers on the surface of hardened steel. The edges of the cracks are raised, giving the surface the appearance of being pulled up. Care must be exercised in passing judgment on this type of crack. If the part is to receive thrust in service, the crack may be of no consequence; however, if the part is subjected to torque, it may be well to reject it. False indications, due to sharp changes in cross section, have a fuzzy outline and show weak adherence of the inspection medium, which may easily be blown off.

(d) *Welds*.—Faulty fusion lines and seams in welds cause the same indications as cracks, and the medium follows the course of the joint. Shrinkage cracks in welds show the same as other cracks. They are usually quite short and irregular. Patch welds, often found in hollow steel propellers, give a very circular type of pattern or spot, which often contains fine shrinkage cracks.

(e) *Cavities and inclusions*.—Cavities and nonmetallic inclusions, of a globular or irregular form, show as spots and are fairly well defined if near the surface. The powder will collect over the whole spot rather than around the edges.

(f) *Scratches*.—Scratches and tool marks are indicated readily by light lines of powder, which often have the appearance of cracks but show little attraction.

(g) Sharp changes in sections, as at fillets, will possess sufficient concentration of magnetic flux to give an appearance resembling a crack, but experience will make differentiation possible.

(3) *Demagnetization*.—As previously mentioned, parts must be demagnetized after each inspection and prior to final cleaning. In all cases, this is accomplished by passing the parts slowly through one of the demagnetizer coils shown in figure 10. When demagnetizing parts that are small in comparison to the demagnetizing unit, care should be used to pass the part close to the coil wall rather than through the center of the opening. Demagnetization must be done after each inspection and before final cleaning.

(4) *Cleaning of parts*.—After demagnetizing, parts may be freed from adhering inspection material by dipping or vigorous “slushing” in the rinsing bath. This operation should be carried out before the inspection liquid has had an opportunity to dry on the surface of the parts.

**49. Maintenance.**—Very little maintenance work is required in connection with the magnaflux equipment. Maintenance consists chiefly in proper care of the batteries and thorough cleaning of the apparatus.

*a. Care of batteries.*—When the magnetizing unit is in constant use, the specific gravity of the batteries should be checked daily with a hydrometer. This reading must not fall below 1.272 (at 80° F.) and the charger should be regulated to maintain this condition. Whenever the electrolyte is found to be less than ½ inch above the plates, distilled water should be added to bring it to this level. The batteries must be kept clean and dry at all times. Batteries may be cleaned by means of a cloth moistened with a solution of carbonate of soda and water. A small amount of petrolatum spread over the terminals will help prevent corrosion.

*b. Cleaning of magnetizing unit.*—The unit should be kept free of all accumulations of dried inspection material by washing with the rinsing solution. In order to assure proper circulation of the inspection medium, the sump screen should be cleaned daily. Due to the high amperage flow, the main contactor points must be kept free of corrosion by frequent cleaning with fine sandpaper.

*c. Miscellaneous.*—(1) Inspection medium should be renewed and the tank cleaned whenever it becomes fouled with dirt, grease, chips, and other foreign material. Should it become low in ferromagnetic content, magnaflux paste should be added.

(2) Pump and motor used for circulating the medium should be checked monthly for lubrication. When necessary the bearings should be lubricated with a suitable cup grease.

[A. G. 062.11 (1-30-41.)]

BY ORDER OF THE SECRETARY OF WAR:

G. C. MARSHALL,  
*Chief of Staff.*

OFFICIAL:

E. S. ADAMS,  
*Major General,*  
*The Adjutant General.*

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(For explanation of symbols see FM 21-6.)









